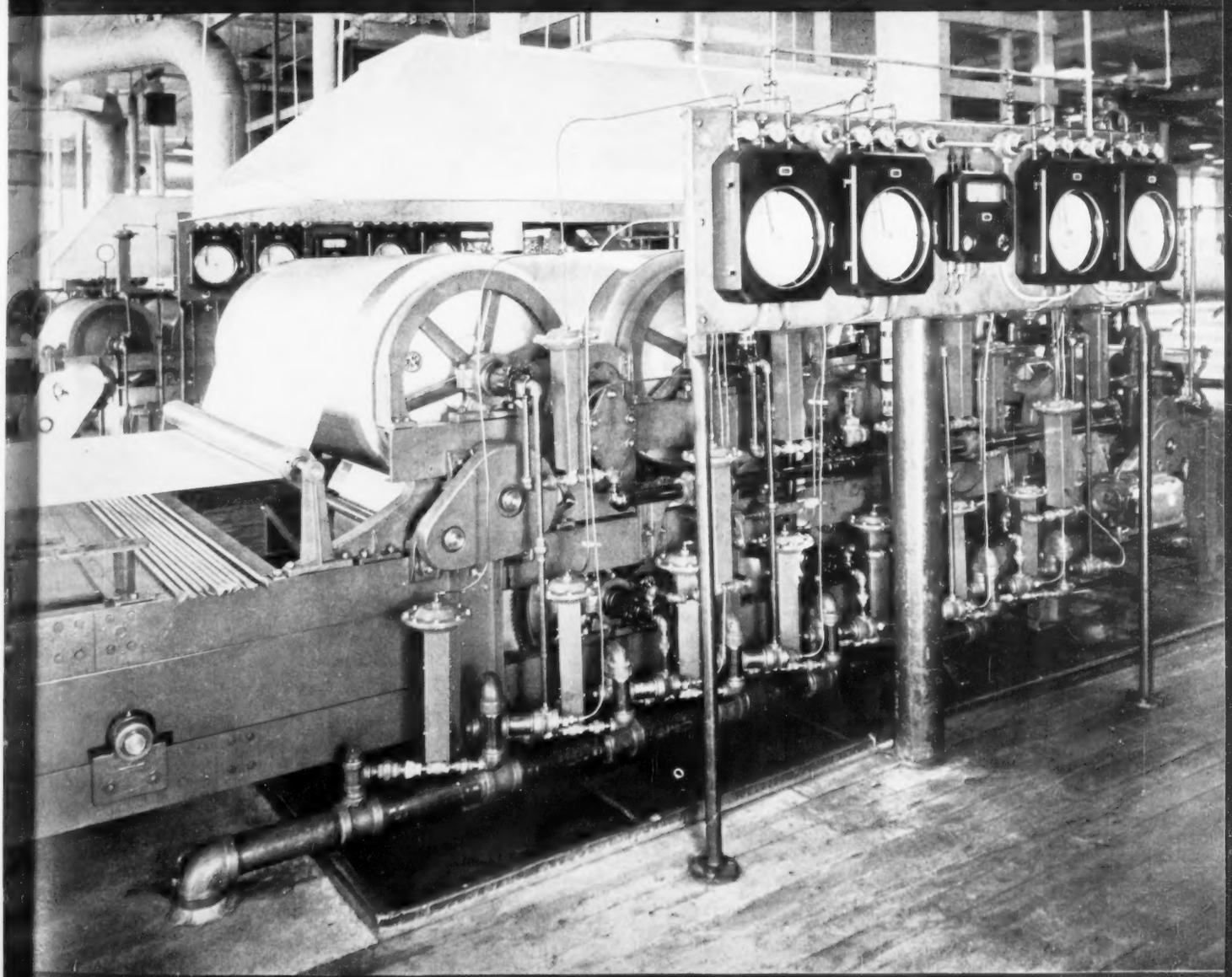
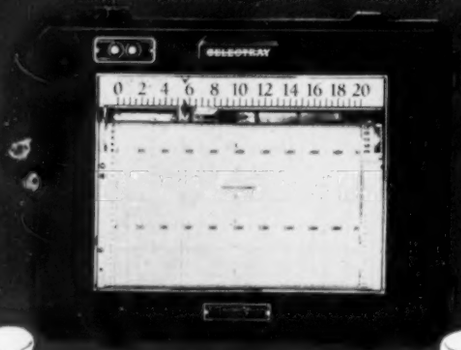
Instruments

THE MAGAZINE OF Measurement and Control

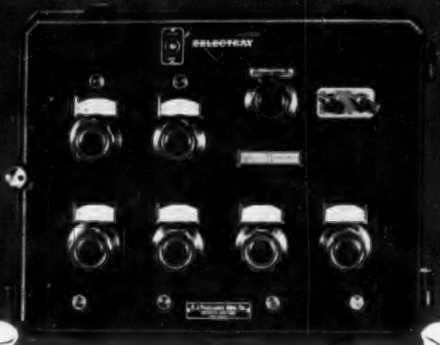
Vol. XIII
FEB. 1940
No. 2



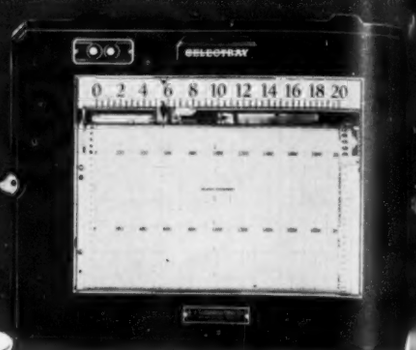
THERE IS A CELECTRAY FOR EVERY LABORATORY and INDUSTRIAL PYROMETER REQUIREMENT



CELECTRAY RECORDER CONTROLLER
for Throttling Electric Heat

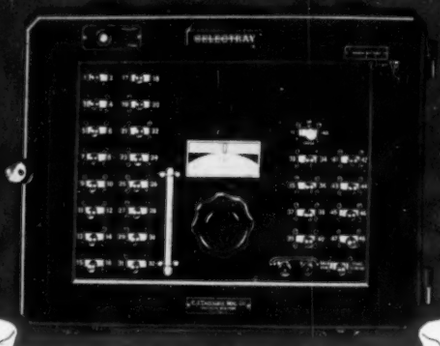


CELECTRAY
6-Point INDICATING CONTROLLER
Also made in 4-Point



CELECTRAY RECORDER CONTROLLER
for Throttling Fuel Heat

CELECTRAY Single Point INDICATING
POTENTIOMETER CONTROLLER



CELECTRAY
48-Point INDICATING CONTROLLER

CELECTRAY Multiple Point
INDICATING POTENTIOMETER

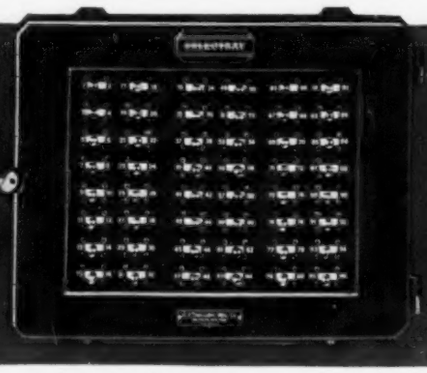
The CELECTRAY principle of potentiometric measurement and control of temperatures has been reduced to practice in many laboratory and industrial applications. Because, the most compelling feature of this notable line of Pyrometers is expressed in terms of their contribution to more precise and economical plant operation.

Today, a new CELECTRAY Controller is providing an economical means for throttling electric heat with no other equipment than is ordinarily used for on-and-off control. This new Controller has no dead zone, and holds a steady temperature without oscillation.

The TAG method of photoelectrically balancing a potentiometer or Wheatstone bridge means higher recording accuracy, increasing the value of CELECTRAY as a precise electrical instrument.

The CELECTRAY Pyrometers shown here include most of the newer models for indicating, recording and controlling. We urge you to get the whole story on these rugged modern instruments . . . learn what their matchless sensitivity, speed and adaptability can do for you in lowering operating expense and raising product uniformity.

CELECTRAY Vibration-Proof
INDICATING CONTROLLER



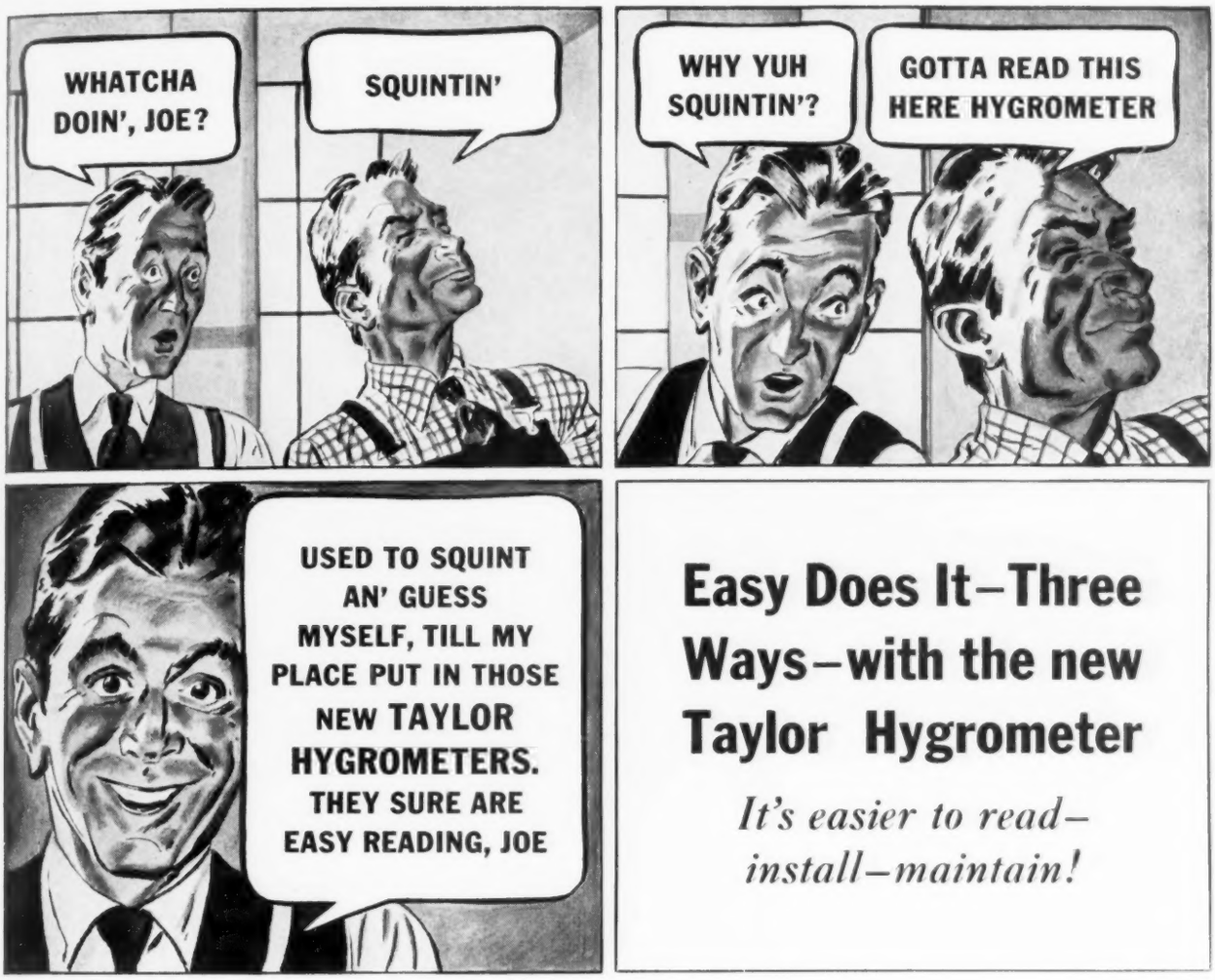
CELECTRAY 96-Point SWITCH BOX

CELECTRAY
Two-Point INDICATING
POTENTIOMETER CONTROLLER

C. J. TAGLIABUE MFG. CO.

Park & Nostrand Ave's., Brooklyn, N. Y.

TAGLIABUE BROOKLYN N.Y. U.S.A.


WHATCHA DOIN', JOE?
SQUINTIN'
WHY YUH SQUINTIN'?
GOTTA READ THIS HERE HYGROMETER
USED TO SQUINT AN' GUESS MYSELF, TILL MY PLACE PUT IN THOSE NEW TAYLOR HYGROMETERS. THEY SURE ARE EASY READING, JOE

Easy Does It—Three Ways—with the new Taylor Hygrometer

It's easier to read—install—maintain!

COMPARE these new Taylor Hygrometer advantages with the disadvantages of other temperature and humidity indicators for air ducts, dryers, and other closed compartments...

Unique tube design—extra-flat horizontal, glass-enclosed scale, with black figures and graduations *etched* on back and lacquered over in orange-yellow for permanent, maximum reading ease.

Double dependability—etched-stem thermometer accuracy and speed plus industrial thermometer ruggedness.

Simple installation—only one 8" x 2¾" duct opening required. Easily detachable mounting sub-plate eliminates risk of breaking.

Instant accessibility—whole unit swings out from mounting, by simply unscrewing two thumbscrews.

Cheap replacement—water bottle replaceable by any stubby beer bottle!

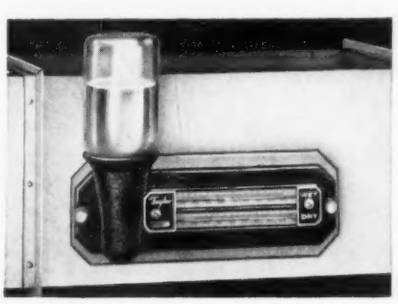
No bulb-conduction error—skeleton-type guard allows free circulation of air across both bulbs—rubber grommets thermally insulate the glass stems.

Quick interchangeability—wet and dry thermometers interchangeable instantly.

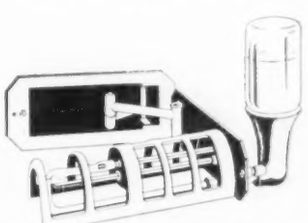
Versatility—available with bottle feed or constant-level reservoir to operate under water pressure or vacuum—wet and dry bulbs staggered for use in horizontal *or* vertical ducts.

Sturdiness—cast aluminum construction—all parts corrosion-resistant.

For completely *trustworthy* performance, install this Taylor Hygrometer. Without obligation to you, get in touch with the Taylor representative, or write Taylor Instrument Companies, Rochester, N.Y. Plant also in Toronto, Canada. Manufacturers in Great Britain: Short & Mason, Ltd., London.



On an air duct . . . See the bottle-feed reservoir of the new Taylor Hygrometer—the Horizontal scales boldly marked in 1° graduations from 30° to 120°F (in 2° graduations from 60° to 220°F., if you desire)—and the rich, brown, crackle finish.



In an "X-ray" . . . See the simple sturdiness of the new Taylor Hygrometer—the cast aluminum construction—the skeleton-like guard permitting free air circulation across both bulbs—and the easy accessibility. just unscrew two thumbscrews and swing it out!

Taylor

Indicating Recording Controlling

TEMPERATURE, PRESSURE, FLOW *and* LEVEL INSTRUMENTS

To Safeguard Your Assemblies

● Whether ten-dollar high-voltage oil-filled capacitor or ten-cent paper tubular, regardless, each and every AEROVOX condenser is *individually tested.* Only in this way can there be no question regarding condenser dependability in those assemblies in which they are incorporated.

And in addition to this individually-tested feature, AEROVOX provides the necessary choice of standard or, in meeting unusual requirements, special types, precisely fitting the given application. You do not have to improvise when you specify AEROVOX.

Submit your problem

● Remember, we offer you our A.A.E. (Aerovox Application Engineering) service at all times. Our engineers will gladly study your application, circuit and all components, and evolve the most satisfactory—and economical—assembly for you.

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Instruments

THE MAGAZINE OF MEASUREMENT and CONTROL

Vol. XIII FEBRUARY 1940 No. 2

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Courtesy Taylor Instrument Companies

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Instrument fuses for meters 1/200 amp. up. Hi-volt for transmitters, etc. 1,000, 5,000 and 10,000 volt ranges, 1/16 amp. up. All types of Littelfuse for aircraft radio, auto, etc. and mountings. Neon testers and indicators. Write for catalog.
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Instruments

THE MAGAZINE OF *Measurement and Control*

M. F. BEHAR, Editor

Is This 1940 or 1840?

IN the *Pittsburgh Sun-Telegraph* of Thursday, January 25th, there was printed a report wired in by J. Allison Bors of the International News Service, who was covering the convention of the United Mine Workers of America at Columbus, Ohio. We quote the following from this INS story:

> Other resolutions adopted, without a record vote, included: * * * *
> Empowered executive board to initiate legislation to tax machinery which displaces men in industry.

This is not the first time, of course, that a labor organization has come out against labor-saving machinery. Such opposition has existed for more than a century. However, in recent years, the nineteenth-century kind of opposition to technological progress—a blind, fierce, unreasoning, instinctive hatred—was giving way to an enlightened attitude. In fact, forward-looking labor leaders aimed their opposition at sudden dislocations rather than at the introduction of labor-saving machines. In recent years, some of these labor leaders have even encouraged the introduction of modern automatic methods in order to enable the employers of their members to lower unit costs, sell more goods, and pay higher wages or assure year-round jobs.

In recent years we had optimistically come to believe that this splendid American spirit would gradually permeate all American labor organizations. In the fall of 1938 we declared that:

> The anti-technology movement is identical with the anti-industry movement. More precisely, it is identical with one branch of the movement against *private* industry. *And it is not the labor movement. . . .**

We were too optimistic! We thought that workers could not be fooled by the rantings of rabble-rousing messiahs who never saw the inside of a factory and whose only acquaintance with machines is with the radio microphone, the mimeograph machine, the printing press and other instruments of propaganda. It would seem that the anti-machine fanatics have succeeded in going over the heads of enlightened labor leaders: by means of the radio and newspapers they evidently have instilled into the rank and file the same old hatreds and fears which a hundred years ago led sometimes to the violent destruction of machinery.

Something sinister seems to be going on behind the scenes. Some destructive influence seems to be at work to start something which will gravely injure *all* of industry: ownership, management and labor alike. While we have our suspicions as to the type of agents exerting this destructive influence, we admit that these suspicions are vague. However, as in all similar critical situations, the first thing to be done by patriotic citizens in order to smell out the enemy is to apply the old reliable test of *cui bono*. Who would benefit?

Let us start by asking who would benefit if taxes were laid on "machinery which displaces men in industry"—as so loosely worded in the empowering resolution adopted by the UMWA delegates.

This question cannot be answered until the UMWA Executive Board drafts a bill to be introduced in Congress or in state legislatures, and makes public the full text of this draft.

From what we hear, the Executive Board is largely made up of men who are or were skilled in the operation of coal-mining, coal-grading and coal-processing machines and instruments.

Gentlemen of the Board! *You* know the extent to which automatic machines have reduced the cost-per-ton of coal and thereby saved *your* industry from being killed by the competition of the newer gaseous and liquid fuels. Don't you consider it your duty as influential members of a financially sick industry to refrain from actions which may aggravate your industry's financial sickness?

Perhaps this is a case for the *cui malo* test: Who would *suffer* if laws were enacted taxing labor-saving machines—that is to say all machines, instruments, controls, etc., which reduce the sum total of human drudgery, which constantly increase the number of good jobs and which otherwise raise the standard of living of all workers?

You, dear reader (and the UMWA), would suffer.

So what? So use last month's issue of *Instruments* as an instrument of counter-propaganda.

*Opening address, Conference on Instrumentation in the Steel Industry.

Exhibit—Instrumentation in Industry

Readers in the Philadelphia, Trenton, Camden and South Jersey area will be interested to know that an exhibit of Instrumentation in Industry, sponsored by the Power Maintenance Association of Southern New Jersey, will be held on March 12, 13 and 14 (Tuesday to Thursday inclusive) in the Camden County Vocational School, Merchantville, N. J. Hours: 3 in the afternoon to 10 in the evening.

Industrial instrument firms, large manufacturing corporations, etc., will occupy the twenty-one principal booths and will display not only commercially-available instruments, control systems, telemetering systems, etc., but also a number of purely educational exhibits. So great will be the number of educational exhibits that we have just been informed (Feb. 7) that the presentation of technical papers has been abandoned, in order that each visitor will have time to view all exhibits pertaining to his own line of work.

Tickets may be obtained free of charge by persons interested in industrial instrumentation. (If you mention that you are a subscriber to *Instruments* you will get immediate service.) Write to J. E. Errickson, Secretary, Power Maintenance Ass'n of Southern New Jersey, 418 Federal St., Camden, N. J.; or to *Instruments*.

How to get there from Philadelphia or Camden: Admiral Wilson Blvd. to the Central Airport traffic circle, then along N. J. 38 to the next traffic circle, then left on Browning Road and you will see the Vocational School on the right-hand side.

"DUCTER"
LOW RESISTANCE
OHMMETER

DIRECT POINTER READINGS
DOWN TO .000001 OHM

For rapid measurements of armature, field and transformer coils, soldered joints, fuses, switch and relay contacts, and other low resistance. Operates from battery. Requires no adjustment for battery voltage. Simply apply a pair of hand spikes and read the scale.

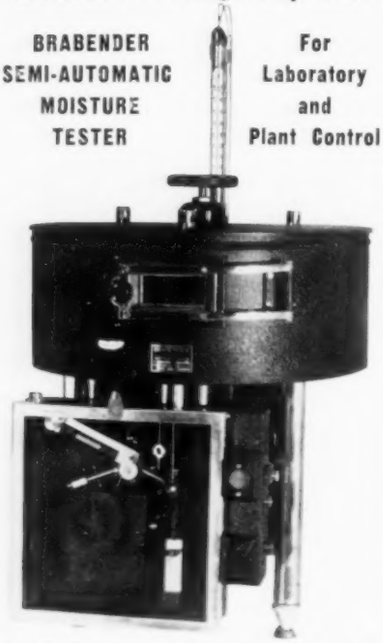
WRITE FOR NEW BULLETIN 1635-I

JAMES G. BIDDLE CO.
Electrical Instruments
1211-13 Arch Street Philadelphia, Pa.

Moisture Testing Simplified

BRABENDER SEMI-AUTOMATIC MOISTURE TESTER

For Laboratory and Plant Control



An ideal combination of drying oven and analytical balance. Requires no training—just push down a lever and read the moisture loss from an illuminated dial—directly in percentages.

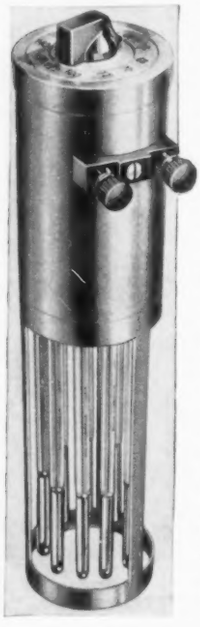
Write for pamphlet

BRABENDER CORPORATION

THE MONTH'S NEW INSTRUMENTS

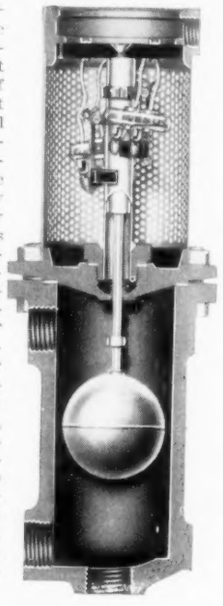
In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions. When writing to manufacturers directly, please mention this department as your source of information. Or write to Information Section, Instruments Publishing Company.

Multi-element Mercurial Type Thermo-regulator



Developed primarily for viscosimeter bath temperature control, multiple-element thermoregulator is an assembly of individual fixed-point mercurial type thermoregulators (eleven in model illustrated) and of a selector switch. Extreme accuracy of fixed-point principle is retained, it is claimed, and obvious convenience of "setting" is added. Replaceability of units permits changing single temperature settings. Model illustrated is 11¼" long by 2½" diam. —*Philadelphia Thermometer Co., 915 Filbert St., Philadelphia, Pa.*

Liquid-level Controller



In new "Magnetrol" automatic liquid level controller, float movement commands action of switching element without mechanical connection—by employing magnetic-coupling principle used successfully for about thirty years in various makes of instruments having primary elements under pressure. Models are available for (1) pump regulation, (2) low-water cut-off, (3) low-water alarm, (4) high-water alarm, (5) high-water cut-off; one for pressures up to 200 lbs./in.²; the other (illustrated) for 550 lbs./in.². — *Fred H. Schaub Engineering Co., 325 W. Huron St., Chicago, Ill.*

High-pressure Oxygen Gage

Case of new special "Duragauge" for high-pressure oxygen service is a heavy brass casting with safety solid front and a full open back. Back of gage is sealed with moisture-proof parer protected by a thin brass disk. Mounting lugs on case hold it away from wall. Bourdon tube is beryllium copper; socket is forged bronze; no steel is used. Accuracy is guaranteed to 0.5%. Gage is provided with maker's new cover of transparent plastic (see *Instruments*, Nov. 1939, page 288).— *Ashcroft American Gauge Div., Manning, Maxwell & Moore, Inc., Bridgeport, Conn.*

Thermoelectric Pyrometers

"Model 70-J" series of thermoelectric pyrometers with Triplett 6"-scale microammeter type electrical indicating instruments (illustrated) is first offering of a newly-formed instrument firm ("not a subsidiary of any other corporation"). Ranges: with copper-constantan couples 0-600°F.; with chromel-alumel couples 0-2000°F. or 0-2500°F. Other scale ranges available on special order (at extra charges in lots of less than 20). Reference junction is in instrument case; automatic compensation by bimetallic method is complete for room temperatures between —20°F. and 115°F. For multiple-point installations there is also announced "Model 10-S-11" double-pole rotary selector switch with silver-alloy studs and contact springs; contact resistance 0.002 to 0.003 ohm; all connections made inside case to eliminate differential-temperature errors. Interchangeability of lead lengths is emphasized in announcement: 25-ft. leads are standard but other lengths up to 75 ft. can be supplied, all having the same resistance, so that indicating instrument need not be re-calibrated unless user greatly alters length supplied. By using multiples of standard leads, extensions up to 300 ft. can be interchanged. —*J-B-T Instruments, Inc., 441 Chapel St., New Haven, Conn.*

Instrument-shunting Mica Capacitors

Bakelite Molded mica capacitors provided with mounting brackets, for the purpose of radio-frequency shunting of instrument windings, are announced. The 3/16" thick brass brackets are mounted and connected to maker's Series 1445-57 mica capacitors. Long slots in brackets permit attachment to terminals of any of the standard panel-mounting instruments.—*Aerovox Corp., New Bedford, Mass.*

EBY

PHOTOELECTRIC CELL
TYPE E-12

Sensitive,
Rugged,
Hermetically Sealed,
Long Life,
High Frequency Response,
Exceptionally Low Internal
Capacity

SENSITIVE RELAY
TYPE ER-12

For Direct Current,
High Speed Response,
Positive Action

Various Coil Resistances
Sterling Silver Contacts

HUGH H. EBY, Inc.
4700 Stenton Avenue
PHILADELPHIA, PA.

Wheelco
RECORDING THERMO-TROL

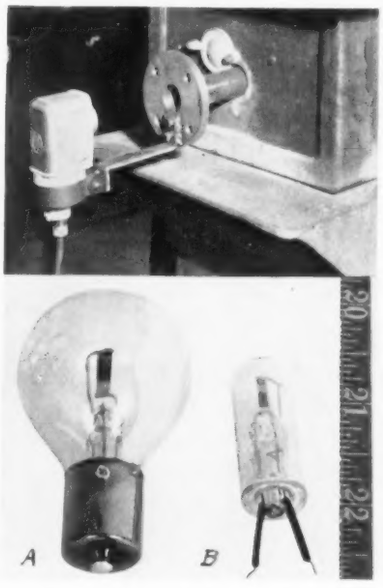
Now the famous Wheelco "Radio Principle" control system, that has been making control history for the past few years, is combined with a highly efficient thermometer recording unit. This control and recording combination especially designed for exacting requirements. The entire unit is enclosed in a dust and fume-proof case and chart is in clear view at all times.

Complete details on request.

Wheelco Instruments Co.
1929-33 S. HALSTED STREET · · · CHICAGO, ILLINOIS

Vacuum Type Radiation Receivers for Pyrometry

New radiation-receiver vacuum thermocouples said to be characterized by exceptionally high sensitivity and rapid response have been designed to fill specific need created by development and use of controlled protective-atmosphere furnaces for processing materials at high temperature. Possible applications include temperature meas-



urement and control in brazing, heat-treating furnaces, glass heat-treating, infra-red drying and solar radiation. Vacuum-enclosed thermocouple consists of a thin filament of dissimilar metals, blackened on one side. Radiant energy acting upon this element produces an emf which is measured by a millivoltmeter or potentiometer which can be calibrated in degrees. Device may be mounted either temporarily or permanently upon a furnace, only accessory needed being a closed-end tube in furnace to prevent fogging of lens and to form a target upon which to sight thermocouple. Temperatures from 300 to 1500°C, can be read on a millivoltmeter or potentiometer; higher temperatures can be handled by the addition of protective screens or filters between thermocouple and heat source. On maker's production lines, new instrument is said to have been found particularly useful in controlling temperatures of rapidly-moving objects and materials on conveyors through furnaces.—*General Electric Co., Schenectady, N. Y.*

Accessories for "L-C Checker"

For the "L-C Checker" (instrument for testing inductances and capacitances—see *Instruments*, Oct. 1939, page 273) there have been brought out two accessories: (1) Mounting brackets which serve to mount Checker on test panel of service shop. (2) Standard mica capacitor of 0.001 mfd. value, used in measuring inductance values with the L-C Checker: it is connected across the coil to be measured, and the resonant frequency of this L-C combination found by using the loop, magnetic coupling or test-prod capacity coupling. A handy self-calculating table in maker's Manual indicates inductance value when using this standard condenser which is fitted with combination binding posts and banana-plug jacks. These accessories, together with the L-C Checker, are now being made available through local jobbers.—*Acravox Corp., New Bedford, Mass.*

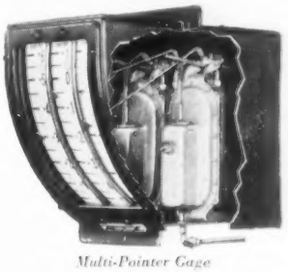
BAILEY METERS

METERS and CONTROL *for Boiler Room Service . . .*

Boiler Meters Indicate, record and integrate Steam Flow from the boiler, record Air Flow supplied for combustion and record Flue Gas Temperature. The use of this meter reduces fuel cost, lessens maintenance and outage, lowers standby costs, and adds capacity.

Bailey Boiler Meter

Multi-Pointer Gages for indicating drafts, pressures, differentials are available with any number of pointers from one to twelve. They are actuated by sturdy yet sensitive diaphragm units.



Multi-Pointer Gage

Flow Meters. For indicating, recording and integrating the flow of steam, feed water, compressed air and other fluids.

Coal Meter

Granular Material Meters For accurately measuring the flow of coal or other granular materials in gravity chutes from overhead bunkers. The total quantity of granular material is shown on a large illuminated counter which may be easily read at a distance of 50 feet.

Control Systems. Make possible the everyday operation of equipment for steam generation and utilization at test efficiencies. They are applied to the control of combustion, feed water, superheat, desuperheat and other factors.

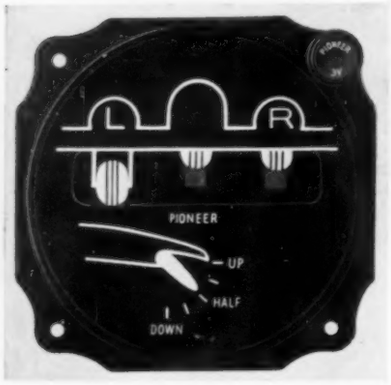
Complete Information on any of the above Bailey products will be gladly furnished upon request.

G-7

BAILEY METER COMPANY
1041 Ivanhoe Rd., Cleveland, Ohio

Wheel and Flap Position Indicator

"Direct Current Autosyn Wheel and Flap Position Indicator" represents a new development in field of remote indicating instruments for aircraft. In maker's previously



available a-c. "Autosyn" transmitter, variation of output voltages with the rotor position is accomplished by varying the inductive coupling between two circuits. This can also be accomplished in a d-c. system by a potentiometer style of resistor. For instrument indications, available torque is usually inadequate. But for wheel and flap position indications, where there is considerable power to drive resistive transmitter element and only intermittent motion, new d-c. Autosyn system makes a light and simple means of remote indication. Transmitters have been designed for the exposed positions where they must operate. Sealing gland on transmitter shaft prevents entrance of moisture and foreign matter. Individual outlets are provided for leads to wheel lock switches to avoid necessity of a junction box. Locating pins are provided so that the mechanic can install and adjust the unit without looking at indicating element. New system indicates on one dial: (1) Position of each of retractable wheels (Pontoon); (2) Action of all locks used to maintain these retractable components in position; (3) Position of flaps.—*Pioneer Instrument Div., Bendix Aviation Corp., Bendix, N. J.*

Mercurial Barometer for Altimeter Calibration

With accuracies of aircraft sensitive altimeters down to ±15 ft., it soon became apparent, states maker, that the contemporary mercurial barometer was far from a usable standard. New Pioneer Mercurial Barometer was developed to be "the finest pressure standard possible." Special glass tubing used is ground to tolerances less than 0.001". A solid brass scale suspended freely from top will not warp with temperature changes. New barometer makes it possible to lay out calculated calibrations instead of comparing new units against a master. Specially designed optical reading system and vernier make it possible to read to 0.01". When it was determined that temperature of mercury lagged temperature of surrounding air by several hours, it was decided to install new barometer in a heat-insulated oven designed to maintain a uniform temperature throughout its entire interior. Thus, when the scale is laid out for oven temperature, it becomes unnecessary to apply temperature correction. All air entering instrument is filtered and dried. Controls are provided outside heat-controlled enclosure to move vernier, to control illumination in optical reading system and to control heaters and circulating fans.—*Pioneer Instrument Div., Bendix Aviation Corp., Bendix, N. J.*

Simplified Design, New Principles

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By F. C. ORCHARD
A.M.I.E.E.

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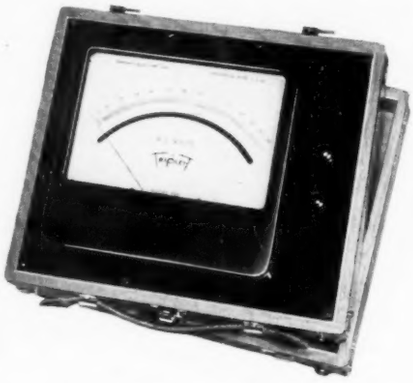
Signal Generator

New "Signalyst" (Stock No. 161) signal generator, designed for radio and television receiver alignment work, has a fundamental frequency range of 100 kc. to 120 Mc. in

10 bands, which is said to be greater than is available on any service test oscillator. Accuracy is ±1% scale calibration. Stray leakage has been minimized. Heterodyne detection is provided for calibration purposes. Signalyst operates on 110-120 volt, 50-60 cycle power supply. Its maximum output voltage is 0.05 volts at low range and 1.3 volts at high range. Features include iron core air trimmer capacitors and adjusted coils wound on low-loss coil forms; die-cast shielded attenuator providing direct reading of output voltage; large three-color dial (90" total scale length); tuning capacitor rotated through gear reduction drives with ratios of 18:1 and 60:1 between pointer and driving knobs; output available at end of a coaxial cable; regulated plate and screen voltage supply. Weight: 21 lbs.; overall dimensions: 9¾" high, 14" long, 8" deep.—*RCA Mfg. Co., Camden, N. J.*

Seven-inch Size Portable Electrical Instruments

New addition to maker's line of electrical measuring instruments is a group of 7" portables, available in standard and special instrument ranges. Models available are of



extreme sensitivity for laboratory use, as well as those for general, commercial and industrial testing purposes. Instrument has a 6" mirror scale, maximum dial opening and knife-edge pointer. Accuracy is within 1% (½% for many ranges). Available in microammeters, milliammeters, ammeters, voltmeters, millivoltmeters, thermo-ammeters—multiple or single range. Case is quarter-sawed golden oak, 11" × 9" × 4", with handle and detachable cover. Black molded panel.—*The Triplett Electrical Instrument Co., Bluffton, Ohio.*

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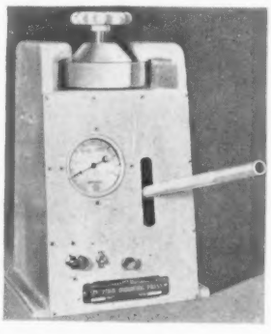


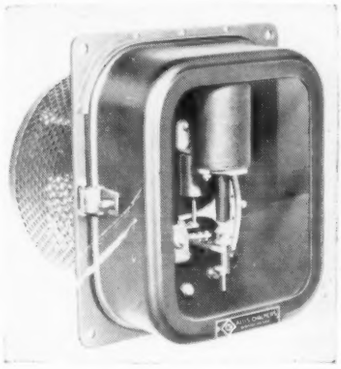
NEW! For metallographic specimens, the Jarrett Mounting Press is as nearly automatic as inventive ingenuity can make such a device. Perfect beveled-edge Bakelite mountings, all of uniform height, are assured. Built-in thermostat assures that all mountings are correctly cured and protects the Bakelite from burning. Press is self-contained; no separate thermometers, no hot or cold molds or other loose parts to handle.

Write for descriptive Bulletin

THE R. Y. FERNER COMPANY
131 State Street Boston, Mass.

Rocking-contact Type Voltage Regulator

New "Type V-11" Rocking-contact voltage regulator, for control of small a-c. and d-c. generators, is said to be even more sensitive, quicker-acting and of greater capacity than company's earlier small regulator models (see *Instruments*, Sept. 1938, page 216). "Streamlined" case now closely harmonizes with maker's larger, more expensive rocking-contact regulators used with larger generators (see *Instruments*, Feb. 1937, page 37). Case is arranged for semi-flush mounting on a switchboard panel or bracket, excludes dust and foreign matter, thereby reducing maintenance. There are no vibrating contacts, tubes or other "parts requiring replacement or readjustment at frequent intervals." Only two simple adjustments need be made at time of installation, all major adjustments being made at factory. Rocking-contact principle incorporated in Type V-11 is said to make it quick acting since it regulates voltage by directly varying resistance in exciter field circuit. New regulator embodies a solenoid-actuated plunger which acts upon a main shaft, rocking a special contact sector over inner surface of a commutator, the segments of which are connected permanently to the regulating resistance. These segments are heavily silver-plated.—*Allis-Chalmers Mfg. Co., Milwaukee, Wis.*



Pocket-size Battery Tester

New pocket-size unit, for correct testing of dry batteries under load, will provide positive data about new batteries as well as batteries in service without need for duplication of any existing test equipment. In same manner as maker's "Model 777" Tube and Battery Tester (see *Instruments*, Dec. 1939, page 313) pocket-size unit has been designed to meet fundamental requirement that when battery shows "good" on instrument scale, it will be capable of delivering sufficient potential when under full load. Condition of battery is indicated in accordance with data from battery manufacturers; and current drain on battery is adjusted to conform to requirements of its particular job. Pin jacks are provided for 1.5, 4.5, 6, 7.5, 45 and 90 volts.—*Weston Electrical Instrument Corp., 591 Frelinghuysen Ave., Newark, N. J.*

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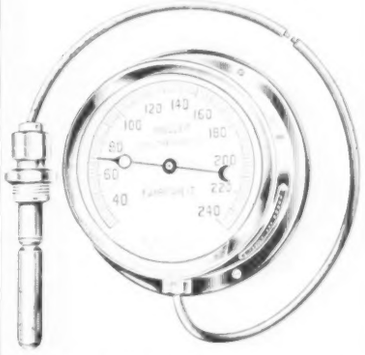
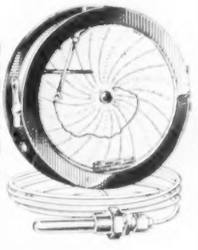


Moeller dial thermometers are made in various scale ranges up to 1000°F. or equivalent in both Metal and Phenolite cases.

Moeller recording thermometers are likewise furnished in various ranges up to 1000°F. or equivalent. Round and square cases, as preferred.



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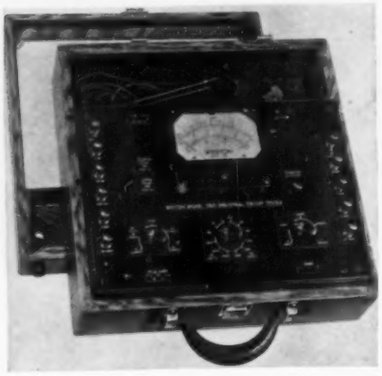
Said to possess unusually wide flexibility of use for individual measurements on all types of control and signal equipment, and electronic apparatus, new "Model 785 Circuit



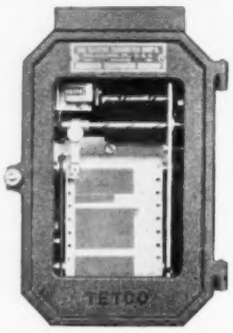
Tester" has 27 complete ranges for voltage, current and resistance measurements. Sensitivity of new instrument permits voltage, current and resistance measurements on oscilloscope circuits. Tester provides d-c. voltage measurements at a sensitivity of 20,000 ohms per volt in ranges of 1/10/50/200/500/1000 volts; a-c. voltage measurements at a sensitivity of 1,000 ohms per volt in ranges of 5/15/30/150/300/500 volts; d-c. current measurements in ranges of 0-50 microamps; 1/10/100 ma.; 1 and 10 amps.; a-c. current measurements available through a self-contained current transformer) in ranges of 0.5/1/5/10 amps.; and resistance measurements in ranges of 3000/30,000/300,000 ohms; 3 and 30 megohms. Resistance measurements are obtained in conjunction with self-contained stock batteries. Instrument accuracy on d-c. voltage and current measurements is 2% (excl. 1000-volt range, which has 3%). Because of the new temperature-compensated rectifier circuit employed, 3% accuracy on a-c. voltage is attained. On a-c. current ranges, 3% on 60-cycle approx. sine wave; other frequencies slightly larger errors. Accuracy on all resistance ranges is 2% of linear arc length on ohmmeter scale. Circuit tester employs a standard unicell on all ranges where any appreciable current is drawn by the ohmmeter circuit. In addition, two 7.5-volt batteries are used to supply energy for high-resistance ranges only. Total drain on these batteries is such that they have shelf life. Test leads are supplied for all voltage and resistance measurements; binding posts for current measurements; arrangement obviates misuse. Case dimensions 13" × 12½" × 5½". Weight in the oak carrying case, incl. batteries, 13½ lbs.—*Weston Electrical Instrument Corp., 591 Frelinghuysen Ave., Newark, N. J.*

Vapor-proof Manifold Pressure Gages for Aircraft

Principal feature of new "Pioneer Vapor-Sealed Manifold Pressure Gauge" is complete isolation of manifold vapors in a chamber containing only the aneroid diaphragm. There is no differential pressure between inside and outside of case or cover glass. Further, every part of mechanism is available without disturbing either pressure-tight or evacuated compartments. Mechanism is covered with dust cap equipped with a miniature air filter that equalizes pressure inside and outside case, preventing dust and moisture from reaching jewelled mechanism. Basic mechanical principles were originally developed by maker for use in "Autosyn Remote Reading Manifold Pressure System." New direct reading mechanism, an adaptation, employs as primary element a

TETCO

Speed Recorder



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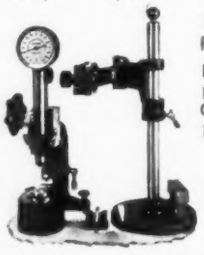

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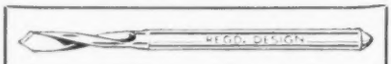

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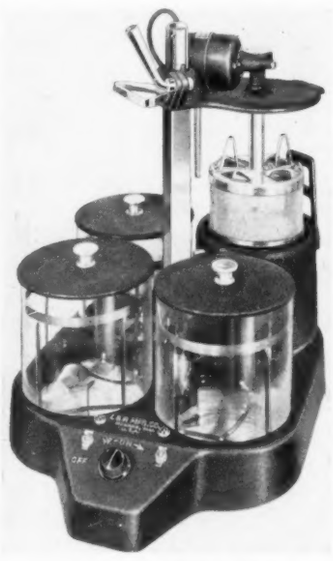
two-cell aneroid diaphragm. Diaphragm and mechanism are supported in a single casting which, when closed by circular backplate, forms pressure-tight compartment for diaphragm. Ball-bearing yoke arm is connected to diaphragm by a flexible tension member of beryllium copper alloy. Opening around yoke arm is sealed by a metallic bellows. Use of a powerful diaphragm provides ample torque for mechanism and a "stiff" pointer results.—*Pioneer Instrument Div., Bendix Aviation Corp., Bendix, N. J.*

Instrument Cleaning Machine and Solutions

For cleaning instrument and meter parts and assemblies properly—and at minimum of direct and indirect costs—there is announced a new method said to be outgrowth



of ten years' experience in meeting requirements of watchmaking, watch-repairing, jewelry and similar fields. Basis of process is a series of cleaning and rinsing solutions, together with a carefully worked-out sequence known as the "cleaning cycle" which includes controlled drying of cleaned parts before they are touched by hand. New "L&R Instrument Cleaning Machine" represents physical form of cleaning-cycle requirements and, although sold outright and without conditions, is offered in conjunction with L&R detergent and rinsing solutions. Likewise, these solutions are announced for unconditional sale but are recommended for use according to the prescribed procedure. Machine is 23" high, weighs 41½ lbs. without solutions. Inside dimensions of Monel work-basket are 5½" diam. by 3⅝" deep. A Monel mesh separator is furnished also, enabling basket to be loaded with small parts.—*The Eastern Specialty Co., 361 North 8th St., Philadelphia, Pa.*

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Available in a number of double range combinations, such as 1 volt and .1 volt, 100 MV and 10 MV, also in pH ranges. Guaranteed accuracy .1%. *An outstanding value.*

Described in Bulletin 270 which also describes *Rubicon* High Precision Type B Laboratory Potentiometer.

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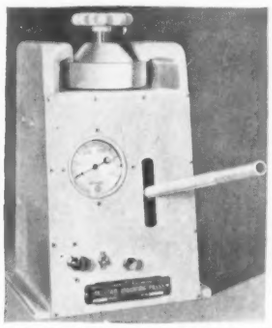
Volt-ohm-milliammeter

New "Model 4922-S Jumbo" volt-ohm-milliammeter, with new 9¼" rectangular instrument, supplements 4" scale length model (*Instruments*, August 1937, page 261) and

"Model 4922 Jumbo" (*Instruments*, Oct. 1938, page 260); has ranges to cover "practically all" applications of electrical measurements: A-c. and d-c. volts, 0/10/50/250/500/2500. D-c. microamps, 0/500; d-c. milliamps, 0/5/50/500. Ohms, 0.05/30 (8 ohms mid-scale), 0.5/10,000 (150 ohms mid-scale), 50/1 megohm (15,000 ohms mid-scale), and 500/10 megohms (150,000 ohms mid-scale). Decibels, —10 to +15, 29, 43. Output, 0/10/50/250/500/2500. This range incorporates a blocking condenser. There is provided an adjustment for change in ohmmeter circuit battery voltage. Change in battery voltage does not affect accuracy of ohm readings. Instrument incorporates a new type of rectifier circuit, which, it is said, will withstand more overload than other types of rectifier circuits.—*The Hickok Electrical Instrument Co., 10514 Dupont Ave., Cleveland, Ohio.*

Specimen Mounting Press

New Jarrett Specimen Mounting Press has been developed especially for expediting this kind of work and is said to make it possible to complete a beveled-edge Bakelite



specimen mounting in ten minutes. Press is self-contained. Only movable part is press head which is placed over mold cavity after it has been filled with red or green Bakelite. On front panel are mounted pressure gage, tell-tale light, current switch and jack release valve. Mounting temperature, controlled by a built-in thermostat, is predetermined and set before press is shipped. It is not necessary to cool mold to complete mounting; controlled temperature protects Bakelite from burning, and 10-min. cycle allows ample time for curing. Press will produce mountings of a constant height, regardless of size of specimen. However, specimens should not exceed ⅝" high or ¾" diam. Pressures of 3000 to 3500 lbs. are sufficient. Mold and the heating elements are insulated from the press frame.—*R. Y. Ferner Co., 131 State St., Boston, Mass.*

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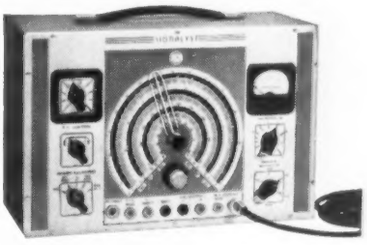
A New Signal Generator Range 120 KC to 120 MC

In Fundamentals



• Dollar for dollar, feature for feature, the new RCA SIGNALYST is the best buy in Signal Generators. Its range is greater than any test oscillator... Its accuracy and stability are excellent...Stray signal leakage is kept at a minimum... AC operated with regulated power supply! It is an instrument that will find many applications in the laboratory in radio and television work.

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All frequencies in fundamentals to 120 Mc ... Magnetite core coils and air trimmer capacitors ... Ladder-type attenuator with meter readings direct in Microvolts ... Large dial (approx. 90 inches scale length). Bands in three colors ... Internal 400 cycle modulation and 400 cycle output available ... D-C connection for standard *as well as* television crystal calibrator, gives direct calibration of instrument ... Suitable for broad band modulation up to 5 MC such as required for television signal modulation ... Regulated plate and screen voltage supply ... Frequency range 100 KC to 120 MC (10 bands), accuracy ± 1%. Maximum Output Voltage: Low Range .05V. High Range 0.3V. Minimum Output Voltage: 100 KC to 15 MC, 1 microvolt; 15 MC to 30 MC, 5 microvolt; 30 MC to 60 MC, 25 microvolt; 60 MC to 120 MC, 50 microvolt.

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Over 350 million RCA radio tubes have been purchased by radio users ... In tubes, as in parts and test equipment, it pays to go RCA All the Way.

RCA **Test Equipment**

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A Service of the Radio Corporation of America

INSTRUMENTS' BOOK SHELF

Applied Acoustics (Second Edition). By HARRY F. OLSON and FRANK MASSA. P. Blakiston's Son and Company, Inc., Philadelphia, 1939. Washable fabric, 6 + 8¾ inches, xviii + 494 pages. Price $5.50

This is a revised and expanded edition of a well-known reference work containing, like the first edition, a comprehensive summary of all of the most important branches of acoustics. The book is liberally supplied with illustrative diagrams and curves, as well as mathematical analyses. The authors' presentation presupposes that the reader is acquainted with elementary physics and electric circuit theory, and, starting from this point, they give a complete but concise review of the many phases of the subject.

In the first chapter fundamental acoustical equations and definitions are described, and the following chapters cover simple dynamical systems and methods of making fundamental acoustical measurements, and the electrical apparatus involved. Common types of acoustical equipment are then described in detail. Included are sections on microphones, telephone receivers, loud speakers, and methods for measuring the characteristics of these various devices. Architectural acoustics, noise measurements, physiological acoustics, and various miscellaneous subjects are also covered.

The section on direct radiator loud speakers has been expanded to include newer types of multi-cone units, bass reflex baffles, and the acoustical labyrinth. A whole new chapter on horn-type loud speakers has been added in place of the rather brief treatment of this subject given in the previous edition.

The chapter on microphones has been expanded to include many of the newer types. Of particular interest is the more complete treatment of piezoelectric or crystal microphones and the additional information on directional microphones, reflectors, concentrators, etc. Additional data have been provided on telephone receivers and the crystal type in particular.

It is naturally impossible for any book covering so many branches of a broad subject to be entirely complete in all sections, but one of the most outstanding characteristics of this new edition is the high degree of completeness which has been attained, particularly in those sections covering work with which the authors have been closely associated. The book contains a wealth of informative material well arranged and of such a character as to be of unusual interest and value to electrical and communications engineers.

The first edition has been generally accepted as one of the best reference works of its type available, and the second edition represents a distinct improvement in regard to both the type and the up-to-date nature of the material covered.

—H. H. SCOTT, *Engineer, General Radio Co., Cambridge, Mass.* (6)

The Microscope—Theory and Practice. By CONRAD BECK. R. & J. Beck, Ltd., London, 1938. Cloth, 5¼ × 8½ inches, 264 pages. Price 7s6d.

In 1923, the second edition of a simple handbook by the same author appeared. This was followed by an advanced handbook (first edition) in 1924. The author has combined the material contained in these two books into a single book, printed on much better paper and with better illustrations. A considerable amount of new material has been added.

The contents of the book are: Geometric Optic of the Microscope; Aperture and Resolution; Photometry of the Microscope; Illumination and Technique; Microscopes, Typical and for Special Purposes; Notes on Testing Microscope Object-Glasses; Polarized Light as Applied to the Microscope.

—RICHARD RIMBACH. (7.7)

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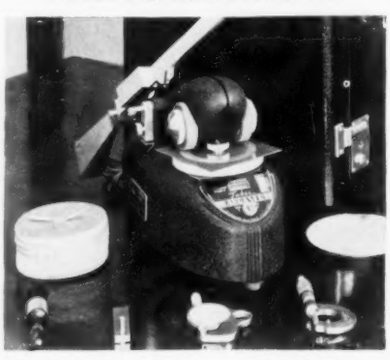

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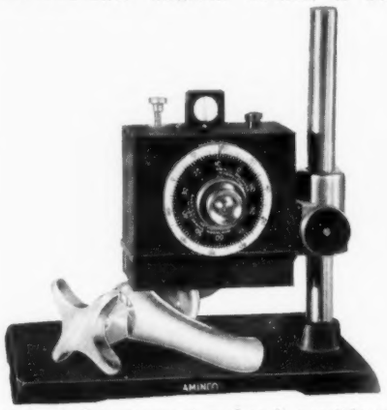
Coating Thickness Tester

New model of "Aminco-Brenner Magno-Gage," an instrument for measuring local thickness of coatings on metals by rapid non-destructive magnetic method, is announced. Improvement makes it possible to measure various types and thicknesses of coatings with only one instrument by interchanging different types of magnets. New model will measure (1) nickel coatings on non-magnetic base metals; (2) non-magnetic, metallic or organic coatings on magnetic base metals; (3) nickel coatings on iron or steel. Method is said to be especially advantageous for both works control and acceptance testing, since it permits testing of a large number of specimens at low cost. —*American Instrument Co., 8010 Georgia Ave., Silver Spring, Md.*



Projectors for 2" × 2" Films

Added to maker's line of moderately-priced projectors for 2" × 2" black-and-white or color films (see *Instruments*, Dec. 1938, page 289; March 1939, page 81) are new 200-watt and 300-watt "Model MK Delineascopes," so that line now ranges from 100-watt to 750-watt. These ratings, however, according to company's statements, do not reveal actual brilliance of projection of which instruments are capable by reason of exceptional optical efficiency. Because each slide may be snapped quickly into position, better "showmanship" in the screening of pictures is effected. Also available is a Film Viewing Device for viewing strips of films preparatory to making up individual slides. —*Spencer Lens Co., 19 Doat St., Buffalo, N. Y.*

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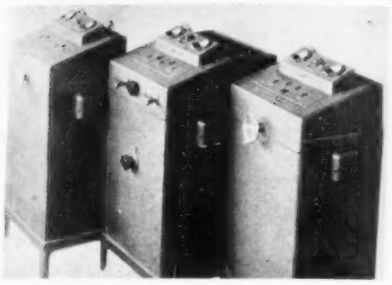
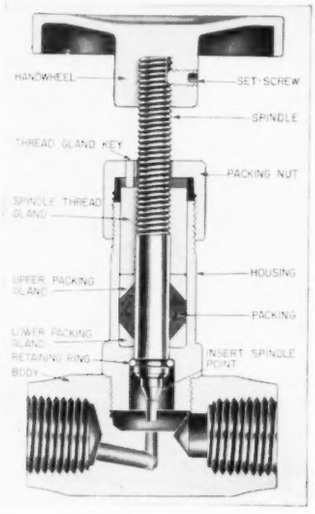
Three electrical power source units for spectro-chemical analysis have been developed to aid in attaining high quantitative analytical accuracy by strict and convenient



control of the conditions of current used to excite the sample being tested. With any of these three units, the error due to light source is minimized. Illustrated are (left to right): 1—3 kw. ARL arc rectifier unit for exciting sample with 250 volts, 4 to 14 amp. d.c. 2—ARL high voltage spark unit for exciting sample with 35,000 volts, 2 kw., a-c. spark current. 3—5 kw. high voltage arc unit for exciting sample with 2500 volts, 2-5 amps, a-c. arc current. Each unit is equipped with voltmeter, ammeter, automatic timer, safety relay, power control and necessary switches all mounted on inclined panel. Units are available to work in conjunction with any type of spectrograph.—*Harry W. Dietert Co., 9330 Roselawn Ave., Detroit, Mich.*

Corrosion-resistant Needle Valves

New corrosion-resistant needle valve incorporates a full-floating spindle: axis of valve spindle is not rigidly fixed in relation to valve body but fixed in relation to spin-



dle thread gland, between which and valve housing there is "a deliberate amount of clearance." This, and elasticity of packing, makes possible alignment between valve seat and spindle point. Valves are machined from 18-8 stainless steel with exception of spindle thread gland (heat-treated chrome steel) and insert spindle points (either chrome steel, Hastelloy C or "Z" nickel, appropriately heat treated). For ordinary conditions, leather packing; other packings for various types of service. Valves are furnished with either V-point spindles (low flow type) or blunt-point spindles for larger flows or for on-and-off service.—*Hoke, Inc., 122 Fifth Ave., New York City.*

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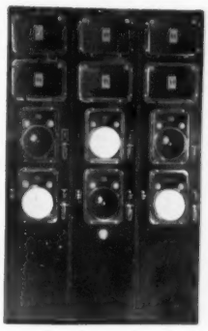

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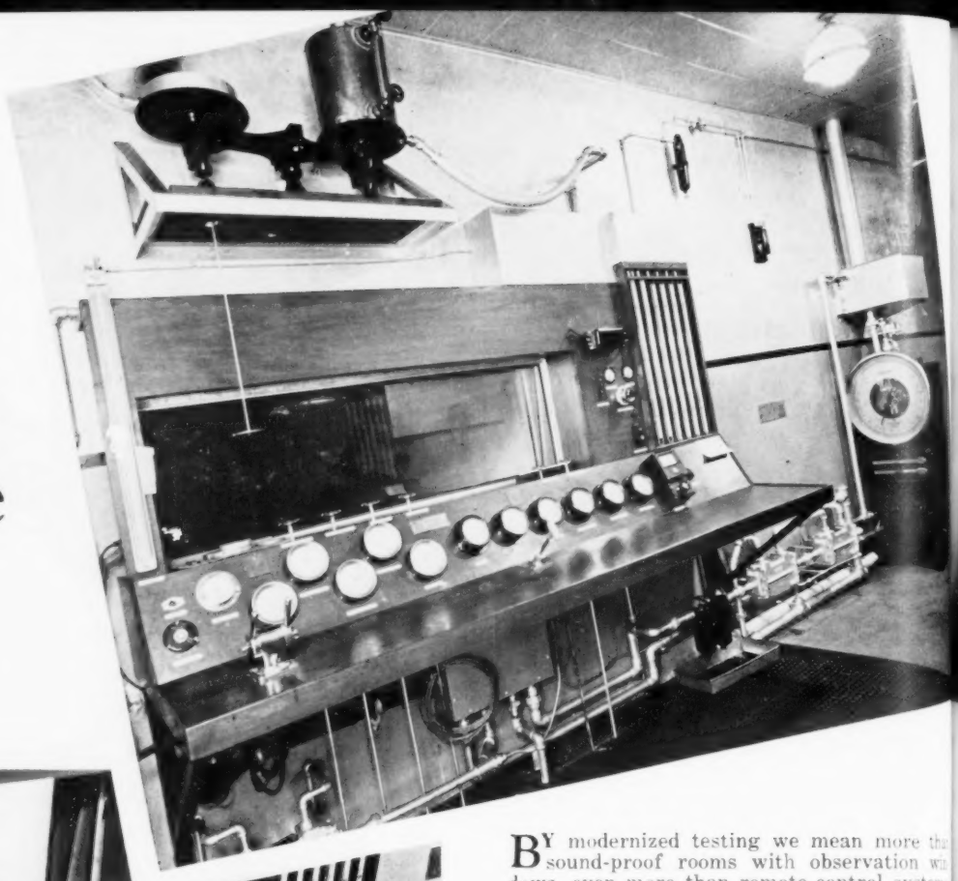
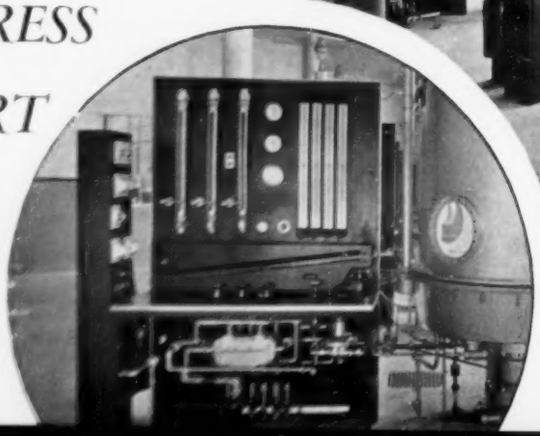
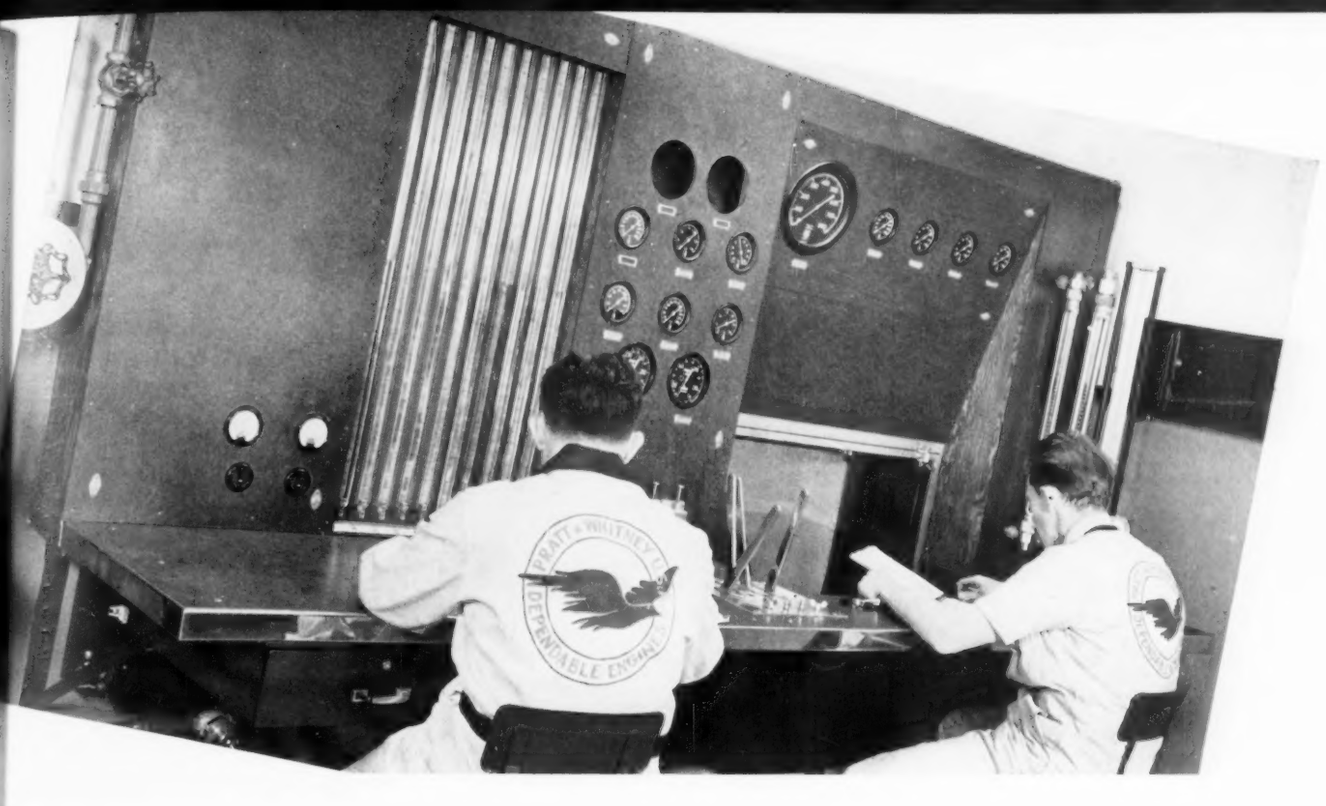


A Pictorial Progress Report

By M. F. BEHAR

BY modernized testing we mean more tha sound-proof rooms with observation wi dows, even more than remote-control system we mean the measurement of every factor i fluencing the performance of the product teste the accurate measurement of even minor fa tors; the continuous measurement of ever factor; the autographic recording of many dat previously logged by hand; and the positive control of every known-and-controllable cond tion—not only when testing components on th ground but when testing assembled ships i flight. These ideals have not all been attaine by all manufacturers or by any one firm. This then, is a brief pictorial progress report rathe





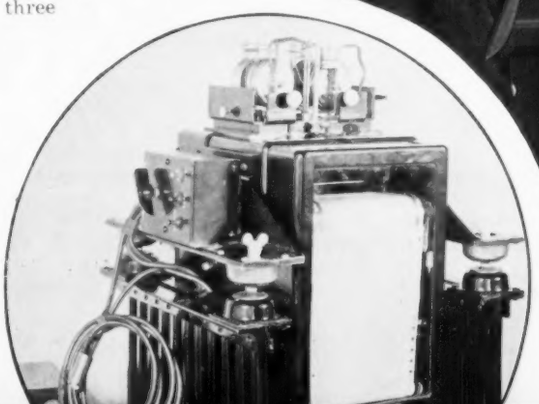
than a description of optimal set-ups. But the aircraft manufacturing industries *did* make great advances in testing instrumentation in the last year. This is true of nearly all manufacturers. Equally true, that much credit belongs to the Army, Navy, N.A.C.A., Bureau of Standards, and other sources of inspiration not engaged in manufacture (including perhaps a little magazine with a big mission).

A complete photographic album of all recent installations everywhere would be monotonously repetitive; so we are confining this February 1940 progress report to the three divisions of testing in which the most rapid progress has been made (ground testing of engines, ground testing of carburetors, flight testing of engines) and to three Eastern manufacturers.

The Wright Aeronautical Corp., Paterson, N. J., sent in the four photographs at the left, with descriptions by H. J. Knell, Engineering Dep't. Top view, "control station for an engine test stand used for the testing of production engines before shipment. The instruments appearing are (left to right): Meriam manometer; starter switch button; magneto switch; Reliance tachometer and revolution counter; engine oil and fuel pressure gages; engine oil, fuel and carburetor air temperature gages; Alnor thermocouple pyrometer; generator control system; manometers—mercury or water." At the extreme left is a close-up of another control station similar to the first. Next, a view of the carburetor test lab showing three of the five units. In the circle, one of these five units: "This equipment is used to determine the fuel metering characteristics of a carburetor under any set of conditions of air pressure and flow through the carburetor. By means of an orifice (at right of air box) and the inclinometer (on lower portion of instrument panel) the flow of air into the box and thence through the carburetor can be determined. Roots blower with water seal provide the air pressure differential through the carburetor. The blower motor and auxiliaries for each unit are controlled by the push-button stations on the left-hand vertical panel. The fuel flow through the carburetor is measured by means of the Rotameters of which there is a selection of three sizes. (Operator selects size for flow range involved.) Various fuel and air pressures or differentials are measured by means of the gages and single-leg manometers. Fuel temperature and pressure are either manually or automatically controlled by the units beneath the control bench."

The United Aircraft Corp., East Hartford, Conn., sent in the photograph above, and the following list: "Left to right: voltmeter and ammeter for generator; ten U-tube manometers; six pressure gages; two dial thermometers; special pressure gage for P&W Torque Meter; four pressure gages for special tests; two fuel flow meters; liquid level tachometer; and inclinometer (black) for measuring carburetor airflow. Behind operator: 56-point thermocouple switch and potentiometer; four engine controls and ignition switch."

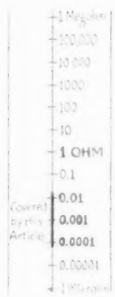
The Glenn L. Martin Co., Baltimore, Md., sent us six photographs of special multiple-pen recorders for flight testing, of component parts thereof, of typical multiple records and of the three men who developed these light-weight recorders by combining Friez and Pioneer measuring and telemetering elements with Esterline-Angus recorder mechanisms: Test Pilot Edward R. Fenimore (left) and assistants Philip N. Bright and W. B. O'Neal. In the circle, close-up of a three-pen recorder minus its remote measuring elements. Some of these employ new principles and will duly be described in our New Instruments Department as soon as aircraft instruments embodying them are made commercially available. One of them deserves mention here: it is a resistance-thermometer element for air temperature but its sensitive portion, instead of being a metallic coil, is a liquid! Yes, an electrolyte with a high temperature coefficient of conductivity. Again does a "source of error" in one branch of instrumentation become the "utilized effect" in another!



Low Resistance Measurements

By G. R. PATTERSON
Assistant Professor of Electrical Engineering,
Carnegie Institute of Technology, Pittsburgh, Pa.

SUCH terms as "high" and "low" are relative; numerical values always depend upon the line of work in which one is engaged. To a plant man concerned with the insulation resistance of his machines, several hundred thousand ohms may be "low"; to the radio engineer interested in modern vacuum-tube circuits, a few thousand ohms; to an electrician working with ordinary field coils or using every-day portable voltmeters, anything less than a hundred ohms. The following discussion pertains to resistances such as those encountered in the armature of a motor or generator, the secondary winding of a transformer, or a sample wire or rod whose resistivity is to be determined; in other words, resistances within the range of 0.01 ohm to 0.0001 ohm.



It is generally known that a special method suitable for several megohms would not be satisfactory for several thousand ohms, and that a method properly used for several thousand ohms would not accurately measure thousandths of an ohm. It is not generally known, however, that within each range there are several methods, of widely different orders of accuracy. Thus, one is confronted with the problem of choosing a method and selecting the apparatus which will efficiently give the desired data with the required accuracy. Under some circumstances the method which would give the greatest possible accuracy would not be practical, because usually the greater the precision the more expensive the apparatus and the more tedious the operation.

Wheatstone Bridge

The generally accepted extreme limits of the range of measurement covered by the Wheatstone bridge are 100,000 ohms to 0.1 ohm. At the extremities of this range, alterations must be made or certain precautions taken to insure accuracy. At the lower limit of a few tenths of an ohm, or even a few ohms, there is danger of overheating one arm

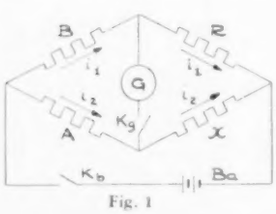


Fig. 1

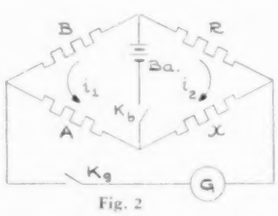


Fig. 2

of the bridge and the unknown resistance which is being measured. Fig. 1 is the usual conventional diagram of connections of the Wheatstone bridge. The diagram has notation as follows: A, B, ratio arms; R, variable arm; X, unknown resistor; G, galvanometer; Ba, battery; K_G, galvanometer key; K_B, battery key. Suppose in this set-up X is a resistance of approximately 1.0 ohm, and Ba is two dry cells in series giving about 3.0 volts; then, ordinarily, A would be 1.0 ohm, B 1000 ohms, and R approximately 1000 ohms. At the balance condition there would be no current through the galvanometer and $i_R = i_R = i_1$; and $i_A = i_X = i_2$. $i_1 = 3/2000 = 0.0015$ amp., and $i_2 = 3/2 = 1.5$ amps. This current of 1.5 amps. through the 1.0 ohm ratio arm and the 1.0 unknown resistor would be disastrous. In the first place, it would cause excessive heating, change the value of the two resistors, and give inaccurate results of the measurement. If this current were permitted to flow for any appreciable length of time, it would no doubt damage or burn out these two resistors. The usual rating of resistance units such as are ordinarily built in apparatus of this type is 0.25 watt per spool. One simple way to attempt to avoid this heating effect is to have the battery connected to the bridge circuit as short a time as possible; that is, in the sequence of operating the battery and galvanometer keys, the battery key should be closed last and opened first. Of course, if the unknown is inductive this procedure would be impossible, as closing and opening the battery key with the galvanometer key closed would give an inductive kick to the galvanometer circuit and make a balance impossible. Another method which usually works well is to interchange the battery and galvanometer connections to the bridge; that is, connect the battery to the G terminals, and the galvanometer to the Ba terminals of the bridge. The method of connection first described is the more sensitive but is also the more dangerous of the two. This second method of connection, while not so sensitive, is usually sensitive enough, and eliminates the possibility of damage due to overheating.

Fig. 2 shows the diagram for this interchanged battery and galvanometer connection. The conditions for balance are the same as before and the values of all resistors would be the same as for Fig. 1. In this second case, at balance, $i_R = i_A = i_1$, and $i_R = i_X = i_2$.

$i_1 = 3/1001 = 0.003$ amp. (approx.)
$i_2 = 3/1001 = 0.003$ amp. (approx.)

Thus neither the low-resistance ratio arm, A, nor the low-resistance unknown, X, would have an excessive current and the heating effect would be eliminated.

Voltmeter-ammeter Method

The Voltmeter-ammeter method is the simplest means of measuring a low resistance; however, if the voltmeter has a low resistance care must be taken that the resistance of the leads and contacts is negligible; also, regardless of the location of the instruments in the circuit, an error exists and if accurate results are desired a correction is necessary.

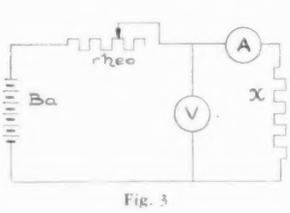


Fig. 3

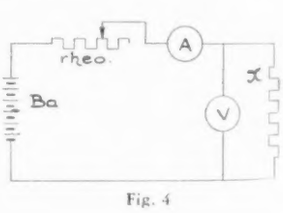


Fig. 4

In the circuit shown in Fig. 3, the voltmeter not only measures the drop across the unknown resistance X, but also measures the drop across the ammeter. In the measurement of resistances of medium value (10 ohms to 10,000 ohms), this drop across the ammeter would be negligible; but in the measurement of low resistance (0.01 to 0.0001 ohm) as considered here, this drop would cause considerable error. Fig. 4 shows the more logical means of connection for this method. In this arrangement error is due to the fact that the ammeter not only measures the current through the unknown resistance X but also the current through the voltmeter. The unknown resistance being low, the current through the voltmeter may be appreciable in value, especially if a low-resistance voltmeter is used; and even though the current through the unknown is high, the drop across it will usually be so low as to require the use of a 15-volt or 3-volt voltmeter or possibly a millivoltmeter; in any case the voltmeter resistance would be considered low for precision results. If such is the case, and a correction is required, it may be easily obtained if the resistance of the voltmeter is known.

$$E_X = (I - E_X/r)X$$
$$X = E_X/(I - E_X/r)$$

where X is the value of the unknown resistance, E_X is the potential drop across X, I is the current, and r is the voltmeter resistance.

However, this method is ordinarily used in shop practice where extremely accurate results are not required and such a correction would not be necessary. If a shop or test floor required precise measurements, it would have other apparatus for easily obtaining these desired results.

Potentiometer Method

The Potentiometer method is essentially the same as the Voltmeter-ammeter method except that a potentiometer is used instead of the voltmeter to measure the drop across the unknown resistance. The current may also be measured by means of a standard shunt and a second potentiometer; placing the shunt in series in the line and measuring the drop across the shunt by means of the potentiometer, the current may be calculated from the values of the potentiometer reading and the calibrated resistance rating of the standard shunt. This is truly a laboratory method; it requires relatively expensive apparatus; and the accuracy obtained may be much greater than required. The potentiometer balance is a null type procedure, and thus the method would require a constant current and would involve time-consuming operations. In this method the possibility of heating error would be considerable for the constant current must be kept on continuously during the entire process of balancing. The use of the Brooks direct-deflection potentiometer would considerably decrease the time required to obtain a balance.

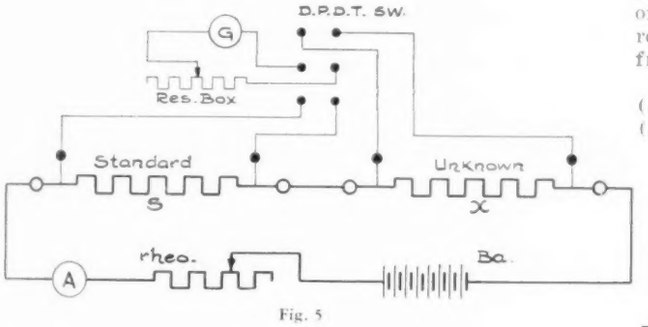


Fig. 5

Comparison of Drops Method

The principle involved in the Comparison of Drops method is exactly as may be implied from its name: the unknown resistance and a standard resistor are connected in series; a common current is passed through the two; and the value of the unknown resistance is determined by comparing the drops of potential across the two.

Many low resistances have two sets of terminals: the large heavy terminals are connected in the line and carry the main line current; the smaller terminals are for the potential lead connections; and it is across these latter two that the rated resistance exists. In measuring the resistance of wires or small rods, the potential terminals may be made by soldering small wires across the rod at the points which give the desired length, any superfluous solder should be removed, or—conveniently—by using point or knife-edge clamps which are supplied with both current and potential terminals.

Fig. 5 shows the diagram of connections for a laboratory setup of the Comparison of Drops method. Using the heavy current terminals the standard resistor and unknown resistance are connected in series with a power supply, a current-regulating rheostat, and an ammeter; connections to the potential terminals of S and X are so arranged that by means of a double-pole double-throw switch the galvanometer may be connected to one and then the other of these resistances; usually a resistance box must be connected in the galvanometer circuit. The procedure is simple. A current which is as large as practical without producing excessive heating is passed through the standard and unknown resistances; the galvanometer is connected to the standard; the resistance box is adjusted to give an on-scale deflection, and the reading is taken; the galvanometer is then connected to the unknown, and again its deflection is recorded. The value of the resistance in the resistance box must be the same for any one set of readings for the standard and the unknown. The galvanometer resistance should be high in comparison to the resistances of the standard and the unknown resistance; such being the case, the current shunted through the galvanometer is negligible in the case of each reading, and it is reasonable to assume that the current through the standard is the same as the current through the unknown. This would be true for this method is applicable only to the measurement of low resistances; here resistances of the order of 0.01 to 0.0001 ohms are considered, and the resistance of the galvanometer would range from about 100 to 800 ohms, depending upon the type.

$$I_S = I_X$$
$$E_S/R_S = E_X/R_X$$
$$R_X = R_S E_X/E_S$$

The galvanometer deflection is proportional to the potential applied to its terminals; thus:

$$R_X = R_S D_X/D_S$$

A practical application may be made of this method by using as the standard a good ammeter shunt whose accuracy has not been impaired by rough handling or overheating; and a millivoltmeter instead of the galvanometer. Ordinarily the resistance box will not be needed. The ammeter shunt and the unknown low resistance are placed in series; a good-sized current is passed through them; and the millivoltmeter is in turn snapped across the two and the readings taken. The value of the unknown is simply the product of the ratio of the two millivoltmeter readings and the resistance of the ammeter shunt, which may be obtained from the current and millivolt ratings of the shunt.

The advantages of the Comparison of Drops method are: (a) it requires a small amount of inexpensive apparatus; (b) it is easily manipulated. The disadvantages of the method are: (a) it requires a constant current, for if the line current should not be the same value when taking the readings D_S and D_X the assumption made in the derivation of the formula would not be true; (b) it requires that the standard and unknown should be somewhat the same value, for if not, one galvanometer reading may be large but the other would be very small, making possible excessive percentage errors of observation; also if they differ greatly the heating in the two may be quite different, or the current shunted through the galvanometer circuit may not be nearly the same in each case.

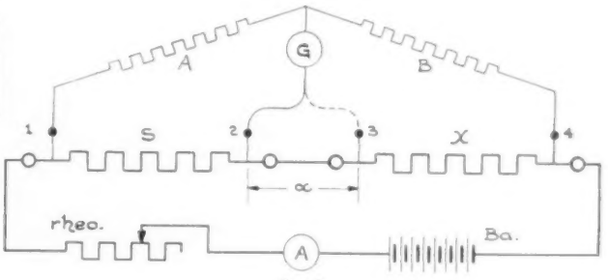


Fig. 6

Modified Wheatstone Bridge Method

The ordinary connection of the Wheatstone bridge is impractical for the measurement of low resistances by reason of errors caused by the lead and contact resistances between the standard and the unknown. Suppose one were to attempt to measure a low resistance by the usual Wheatstone bridge method; then, referring to Fig. 6, the lower galvanometer connection must be made to either terminal 2 or 3. Assume, for simplicity, that the standard is 0.001 ohm, the unknown low resistance approximately 0.001 ohm, and the lead and contact resistance between S and X, ∞, 0.001 ohm. If the

lower galvanometer connection is made to terminal 2, α is added to X; if it is made to terminal 3, α is added to S. In either case the apparent value of one of these resistors is doubled, giving rise to 100% error; as a matter of fact, in the actual performance of such a test the error is many times greater than 100%.

In the Modified Wheatstone Bridge method this error is eliminated by connecting the lower galvanometer lead first to terminal 2 and then to terminal 3. The apparatus is connected as shown in Fig. 6, the galvanometer lead is connected to terminal 2, resistance box A is usually set at a fixed value, say 1000 ohms, resistance box B is adjusted until there is no galvanometer deflection; then the galvanometer lead is shifted to terminal 3, the value of A is unchanged, and B is again adjusted until there is no galvanometer deflection. The value of the unknown low resistance may be calculated by the formula:

$$X = S \times B_3/A \times \frac{(A + B_2)}{(A + B_3)}$$

This method may be made highly practical by using a good ammeter shunt for S, a reliable 1000-ohm resistor for A, and a plug or decade box for B; the indicating device may be a galvanometer or millivoltmeter of sufficient sensitivity. The Modified Wheatstone Bridge method is rather simple to perform and does not require any special elaborate apparatus; however, the computations are a little more complicated than for most other methods; the lead connecting the standard and unknown should be of extremely low resistance and its connections must be secure and stable, as any slight variation in α would introduce considerable error.

Kelvin Double Bridge Method

The Kelvin Double Bridge is the most satisfactory and convenient method for the accurate measurement of low resistance. It is the generally accepted method for comparing low resistance standards, for determining electrical resistivity, conductivity and temperature coefficient of conductors, for measuring the resistance of the windings of large motors, generators, and transformers, and for measuring temperature of low-resistance windings. The Kelvin Double Bridge differs from the Wheatstone Bridge in the addition of two additional resistances, which are placed in series and shunted around the lead and contact resistance which exists in the connection between the standard and the unknown resistance. The contact resistances at the potential terminals are negligible as they are in series with the resistors of the ratio arms, which have a resistance of at least several hundred ohms. Thus for the measurement of low resistance, the errors which would exist in the ordinary Wheatstone Bridge and the necessity of shifting the galvanometer lead as in the Modified Wheatstone Bridge are eliminated. As in the other methods described, there must be a current-regulating rheostat in the main line, as the standard and unknown are of very low resistance. Since the sensitivity of the bridge increases proportionally with the current through the standard and unknown resistance, this current should be as large as is permissible by the current-carrying capacity of S and X. Here, as in all other resistance measurements, it is necessary to note the temperature at which the measurements are made, as the resistance of most conductors varies with their temperature.

There are two common types of the Kelvin Double Bridge, the one operating with variable values of the ratio arms and a standard of fixed value, while the other has fixed values of the ratio arms and a variable standard. With the connections as shown in Fig. 7, the following relation exists:

$$A/B = a/b = X/S$$

By nature of the derivation of this proportionality, the ratio A/B must always equal the ratio a/b; the simplest way to accomplish this is to always have $A = a$ and $B = b$; then:

$$A/B = X/S$$
$$X = A/B \times S$$

The bridge is so constructed that any changes in the current or potential do not alter the proportion $A/B = a/b$. Thus it does not require a constant current supply.

The procedure for measurement is as may be implied from the description of the two types. In the one form, the bridge may be made of four high-grade variable resistance boxes, range 1 ohm to 10,000 ohms, and a calibrated low-resistance standard of fixed value. Standard resistors may be designed for immersion in an oil bath for accurate temperature control, a certificate of accuracy is usually furnished by the maker, and a calibration covering a wide range of normal temperatures may be obtained from the National Bureau of Standards. If such precision is not necessary, a good ammeter shunt may be used. The current is adjusted to a value as large as is compatible with accuracy and the resistances of the ratio arms are adjusted until there is no galvanometer deflection, remembering that A must equal a, and B must equal b. A convenient way to obtain this balance is to set B and b at 1000 ohms each and adjust A and a, then the computation of X is simple from $X = S \times A/B$.

In the other form of the bridge the ratio arms are made of resistors of fixed value and the standard is an adjustable low-resistance standard. One manufacturer of apparatus for resistance measurements (Leeds & Northrup) makes a Kelvin Double Bridge ratio box with fixed resistors of 100, 300, 400, 1000, and 10,000 ohms for each of the two arms, these resistors being placed in the circuit by plug and block connectors making possible ratios of 0.01, 0.1, 1.0, 10, 100, and other odd ratios not ordinarily used.

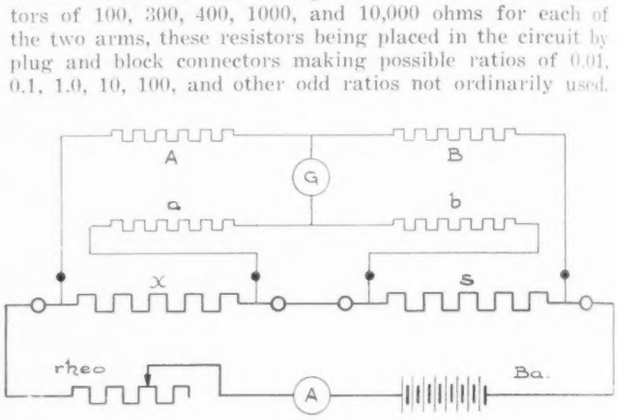


Fig. 7

Their low-resistance standard consists of an 0.0011-ohm calibrated bar, with a vernier adjustment of the knife-edge contact, in series with nine fixed resistors of 0.001 ohm each. This combination is equivalent to an adjustable standard ten times as long as the bar alone. This apparatus is capable of measuring resistance from 1.0 to 0.00001 ohm down, and the bridge can be balanced to a precision of 0.04% down to 0.000,025 ohm. The limit of error is 0.04% or better for ordinary resistance measurements down to 0.0001 ohm. The procedure for measurements consists simply in setting the ratio arms to their proper value and adjusting the standard for a galvanometer balance.

The above-described apparatus is more suitable for laboratory practice. For test floor measurements of low resistances, such as transformer and large electric machine windings, the Portable Kelvin Bridge is most accurate and efficient. The previously-mentioned maker supplies a Portable Kelvin Bridge with a range from 0.0001 ohm to 26.6 ohms; the limit of error is 0.2%, 0.0005 ohm to 26.6 ohms; and 0.4%, 0.0001 to 0.0005 ohm; the overall dimensions are 16" × 8" × 6¾" and the weight 13½ lbs.

A third method of balance of the Kelvin Double Bridge, when the unknown and the standard resistances are somewhat the same in value, was devised by Dr. William R. Work, Professor and Head of Department of Electrical Engineering, Carnegie Institute of Technology, and has been in use for several years in the C.I.T. measurement laboratories. The diagram of connections for this method of balance of the Kelvin Double Bridge is shown in Fig. 8. The general scheme is the same as in the ordinary double bridge, except that both the ratio arms and the standard have fixed values, and there is an auxiliary battery circuit in parallel with the standard resistor. The units of the ratio arms may be 1000-ohm resistors; S should be a standard resistor nearly equal in value to the resistance of the

Continued on page 62

Physical Processes Which Occur at the Point Where a Hardness Test is Made

By S. R. WILLIAMS
Professor of Physics, Amherst College

Inasmuch as we measure hardness (1) by the diameter of the imprint made by a steel ball under a given load, as in the Brinell instrument; (2) by the depth of impression made by a steel ball under a definite load, as in the Rockwell hardness tester; (3) by the width of a diamond cut under a fixed load, as in the Bierbaum standard instrument; (4) by the load to give an arbitrary chosen width of cut, as in the Graton machine, or, in general, (5) by the permanent (or temporary, as in the Shore instrument) deformation arising in the process of indentation; it behooves us to consider carefully the factors which enter into the indentation processes to make them vary in one material from those in another. It will be the province of this article to study some of these physical processes which go on when we make a hardness test.

The most obvious physical process which meets the eye when an indentation is made in a hardness test is the "piling-up" or "sinking-in" of the material around the edges of the imprint. These various displacements of material have been carefully studied by numerous investigators[1] and are graphically shown in Figs. 211 and 212. Not only are the various forms of displacements indicated, but also the kinds of materials which are likely to show characteristic forms of "piling up," "sinking in" or "flattening".

Fig. 213 is a photograph of the piling-up effect around the indentation made by a Rockwell tester in a piece of soft steel.

The meteor crater, near Winslow, Arizona, shows such a piling-up effect on a large scale. See Fig. 214. The material which was formerly in the space now occupied by the present hole had to go somewhere. It was neces-

[1] A. L. Norbury and T. Samuel, Brinell Test. *Journal Iron and Steel Institute*, Vol. 117, 1928, pages 673-687.

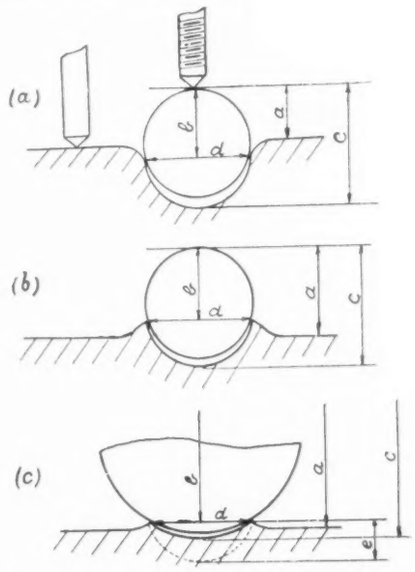


Fig. 211. Spherometer measurements of Brinell impressions. (a) Sinking-in. (b) Piling-up. (c) Flattening.
a is obtained from spherometer readings;
b is calculated from *a* and *d* (diam. of impression measured with a traveling microscope) and the radius of the steel ball resting in the impression;
$b - a$ = sinking-in in Fig. (a);
$a - b$ = piling-up in Figs. (b) and (c);
c is obtained from spherometer readings;
$c - b$ = measured depth of impression;
e (Fig. (c)) = depth of impression, calculated from measured diam., assuming 5-mm radius of curvature;
$e - (c - b)$ = flattening, i.e., difference between depth calculated from diam. and measured depth.
From Norbury and Samuels, *Heat Treating and Forging*, December 1923

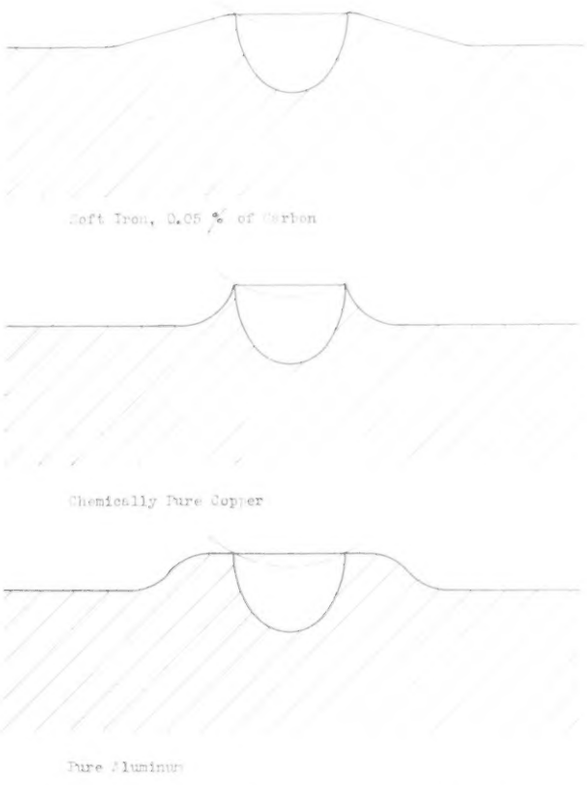


Fig. 212. Craters produced in various metals by a ball indenter.
Courtesy of *Engineering Progress*

Fig. 213. Piling-up effect around the indentation made by the 1/16" ball of a Rockwell Hardness Tester. The metal is soft steel.

Fig. 214. Meteor Crater near Winslow, Arizona shows a "piling-up" effect around the rim of the indentation.

Science Service Photo

Fig. 215. A photoelastic stress pattern for a concentrated load on a large thin plate. The black and white bands (isochromatic lines) are contours of equal strain differences.

Courtesy Prof. M. M. Frocht, Carnegie Inst. of Tech.

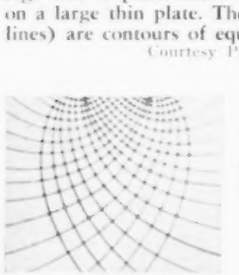


Fig. 216. Slip lines for a concentrated, constant pressure acting along the edge of a metal plate.

Courtesy *Civil Engineering*

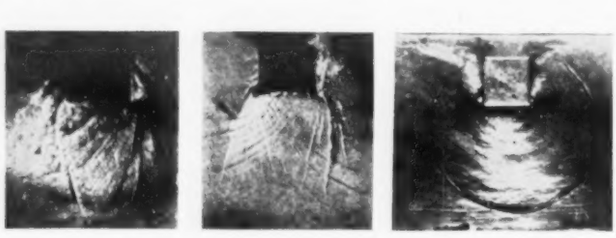


Fig. 217. Formation of slip lines in layers of moist soil under pressure.

Courtesy *Civil Engineering*

sary either to compress the material—make it denser—or else have it bulge up around the edge of the imprint. No doubt both effects occurred, but the piling-up is today the most obvious. It is not difficult to picture this movement of the various portions of the earth near the indentation. Because of its quality and structure, the particles of the earth were crowded together directly under the impacting meteor. The pressure thereby developed pushed the earth material sidewise and rolled it out from under the meteor and pushing upwards formed a wall, a piling-up around the rim of the crater.

There are other illustrations which give us some knowledge about the distribution of the strains in a substance undergoing an indentation of the surface by a hardness tester. We are interested in the strains because they represent the permanent deformations and it is in terms of permanent deformations that, in general, we measure hardness.

Through the courtesy of M. M. Frocht[2] there is shown in Fig. 215 a photoelastic strain pattern for a concentrated load on the edge of a large thin plate of Bakelite. A small metal cylinder with its axis normal to the plane of a thin sheet of transparent plastic is pressed into the edge of the plate. The stresses produced by the cylinder set up definite strains in the sheet and so long as the external stresses are maintained produce persistent deformations in the plastic. When plane-polarized monochromatic light is sent normally through such a plate and the light is viewed by means of an analyzing system, alternate dark and light bands appear in the field of view which are the contours of equal strain differences. In Fig. 215 it must be emphasized that these isochromatic lines are shown in only two dimensions—in fact are almost set up in only two dimensions since they are produced in a thin plate; whereas the problem of the strain patterns under a spherical indenter in a large block of steel, for instance, is one of 3-dimensional form. The strain distributions in a 2-dimensional system has certain similarities to that in a 3-dimensional set-up but it also has many acute differences. The strain system under a steel ball indenter cannot be completely shown by any such process as indicated in Fig. 215, nevertheless, it is suggestive of how the 3-dimensional system would look.

Of perhaps greater interest and importance in a study of the penetration processes of a hardness tester are the slip lines which are produced and may be seen when the indenter penetrates the surface of the test material. In Fig. 216 are shown the slip lines for a concentrated constant pressure acting along the edge of a metal plate as drawn by Nadai[3]. This is for a square faced indenter. The slip lines for a spherical-faced indenter would be similar, but evidently the tendency to bulge up and around a spherical indenter would be greater than the square block shown in Fig. 216.

In Fig. 217, Krynine[4] has studied these slip lines in various kinds of moist soils. Fig. 218 shows the form of the strain area as a whole developed under a penetrator similar to that in Fig. 217. In all three pictures the study has been carried out at the edge of a thin layer of moist soil, analogous to the study of the isochromatic lines in Fig. 215.

Fig. 218 also indicates the shape of the strain area under a large building or under the pier of a large

[2]M. M. Froch, A Study of Photoelasticity and a Photoelastic and Theoretical Investigation of the Stress Distribution in Square Blocks Subjected to Concentrated Diagonal Loads. *Transactions A.S.M.E.*, (Reprint 15 pages) Vol. 53, 1931, Section APM-53-11, pages 135-153.

See also—J. H. Evans, Photoelasticity—A Short Explanation of the Optical Principles Involved. *Civil Engineering*, Vol. 3, 1933, pages 571-573.

[3]A. Nadai, Plasticity. Figure shown in an article by—

[4]D. P. Krynine, Some Shear Phenomena in a Loaded Soil Mass. *Civil Engineering*, Vol. 3, 1933, pages 574-576.

ridge, both of which may be considered as an earth indenter.

This movement of the material underneath and around an indenter may be observed in the device shown in Fig. 24, a, b and c. (April 1937 instalment.) It is for the most part a movement along slip planes, which in the case of an actual indenter, like the Rockwell, manifests itself by slip lines already shown in Figs. 216 and 217. In order to make the outfit in Fig. 24 more like the indenter of a hardness tester and less like a punch the square, wooden blocks, which served as the edges to the jaws of the punch, are removed in Fig. 219. When the indenter p is pushed in by means of the screw S, the steel balls will be seen to move straight ahead at first and then along diagonal lines or slip planes. As some of the balls move out along diagonal lines, others push to the right and slip around to the side of the indenter and push up the surface indented as observed in the photograph shown in Fig. 214. The curved lines drawn on the photograph in Fig. 219 represent crudely the slip lines or trajectories along which the principal shearing stresses operate to produce the strains or deformations. Here again we are dealing with a 2-dimensional frame in which the outfit is laid in a nearly horizontal position with the p side raised a little higher than the opposite one so that a component of the force of gravity acting on the balls may simulate the elastic forces operating in solids, for instance a metal, when the penetrator sinks in.

Thus far we have been studying models for the purpose of picturing to ourselves the strains or deformations which occur under an indenter; what can we observe visually and photographically under actual working conditions with a Brinell, Vickers or Rockwell hardness tester as the steel ball is pushed into the surface of a test specimen?

Figs. 220 and 221 show the imprint of a large steel ball indenter on the surface of a hot-rolled strip of steel in which the surface is coated with a layer of oxide. The slip lines are plainly discernible as one section shears past the other and breaks off small flakes of the oxide. The two photographs are for different sized steel balls and both show the same results. Figs. 220 and 221 should be compared with the slip lines in Figs. 216 and 217. The slip lines in Figs. 220 and 221 run out horizontally from the periphery of the indentation but we know from other observations that they run down into the body of the material as they did in the moist soil in Fig. 217. Attention should be drawn to the fact that in Figs. 220 and 221 some of the slip lines start out to encircle the imprint in a clockwise fashion while others run out counter-clockwise. In a fine structure these lines would overlap one another so thickly that they would appear as a clouded surface on the material. This may be seen in Fig. 213 for a polished soft steel surface.

In order to study what actually occurs within the metal and under the indenter, two pieces of steel were carefully smoothed off (in some cases with a plane mirror finish) and clamped together by means of screws as shown in Fig. 222. Along the line separating the two surfaces, indentations were made with a Rockwell Indenter. Such an imprint is shown in Fig. 213. On separating the two surfaces, one sees something of what is occuring within the metal under the indenter.

In Fig. 223 are shown, highly magnified, photographs of (a) the top surface of one block and (b) the side view of the same indentation. In a piece of soft steel the slip lines are so close to one another and criss-cross one another to such an extent that the surface appears clouded out to a definite distance from the edge of the

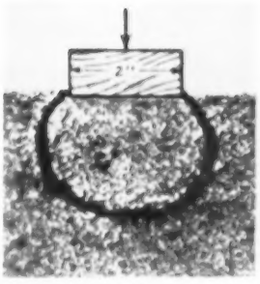


Fig. 218. Bulge produced in a layer of moist Ottawa sand 1" thick by pressing against its edge a wooden plate 2" wide.

Courtesy Civil Engineering

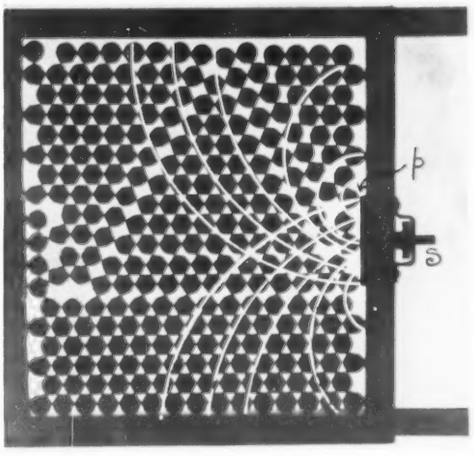


Fig. 219. Roughly, the slip lines have been drawn in with white ink. These are for a concentrated, constant pressure along the edge of a metal plate. See also Fig. 216.

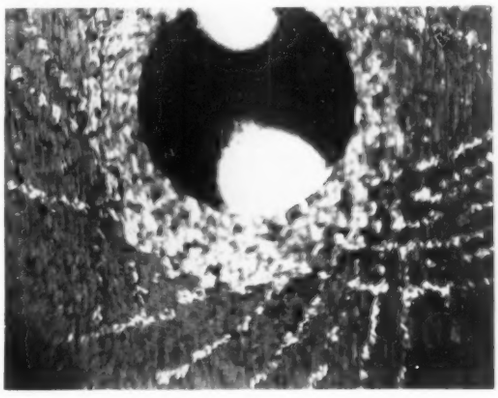


Fig. 220. The surface slip lines around the periphery of an imprint of a steel ball made in the surface of a piece of hot-rolled steel. The lines are produced by shearing in the oxide layer on the surface of the steel.

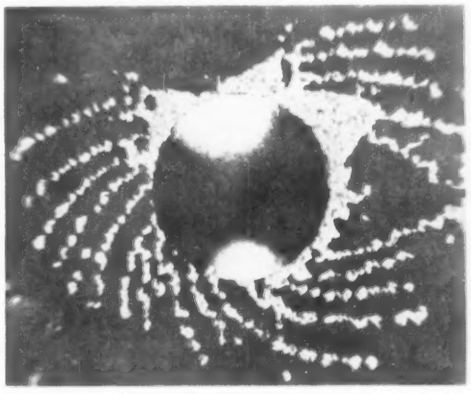


Fig. 221. The surface slip lines in a piece of steel produced by a smaller ball than used in Fig. 220.

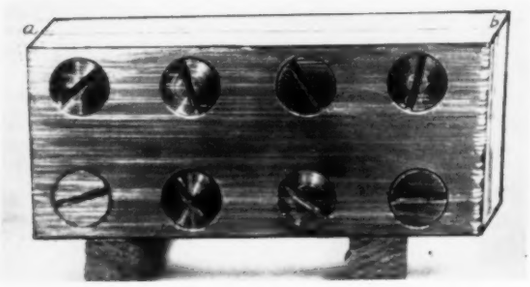


Fig. 222. Two polished surfaces of metal are held rigidly together by a number of machine screws. Indentations are made along the crack between the two pieces as shown in Fig. 213.

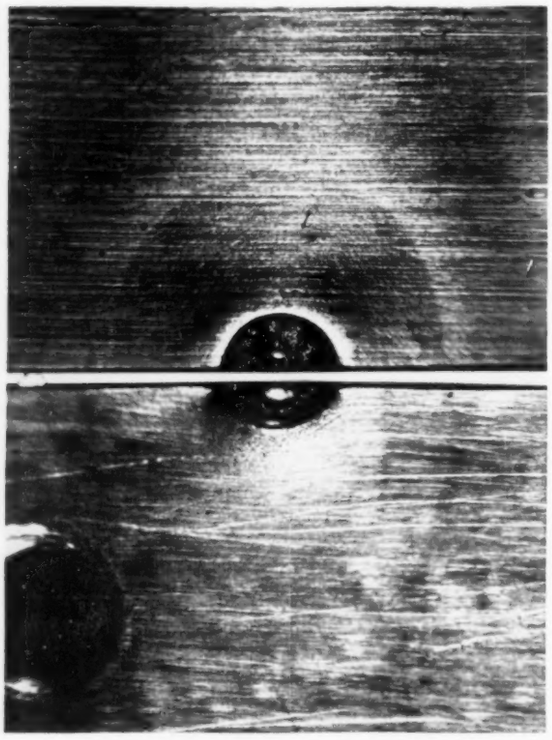


Fig. 223. The upper half of this picture (a) shows the top surface of one block attached to the other as in Fig. 222 and on which an indentation has been made. Only half of the imprint shows when the blocks are separated. The lower part of the photograph (b) gives a side view of the same imprint. The sharpness of the outer edges of the disturbed areas around the imprint in both cases is an outstanding feature.

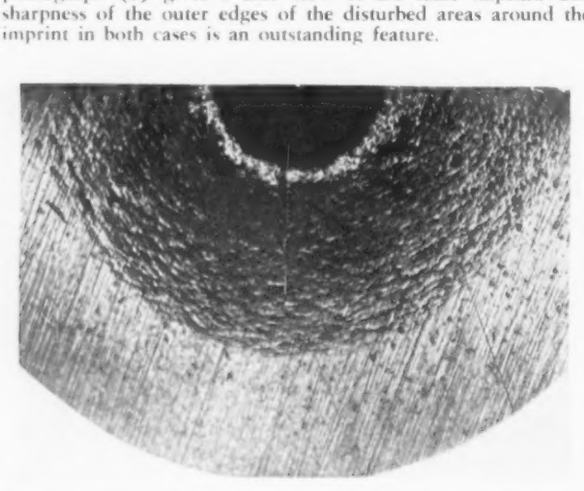


Fig. 224. Oblique illumination of the indentation of a Rockwell Hardness Tester on a block of steel. Note the sharpness of the outer edge of the area disturbed by the indenter.

imprint of the ball. The termination of this disturbed area is sharply defined as shown in (a), Fig. 223. Fig. 224 shows this sharpness of the outer edge of the disturbed area when the indentation was made in the surface of a single block of soft steel and not on the crack between two pieces as in (a) Fig. 223. In (b) Fig. 223 is shown a side view of the indentation of a steel ball indenter. The surface was left in a straight-lined, scratched condition in order to show the bending of these lines as the ball sank into the metal. The outer surface of the disturbed portion is again shown to be sharply defined. This is in reality a 2-dimensional system, for no matter how closely the two pieces fit together the strains cannot be transmitted across the boundary in exactly the same way as though the two were one solid block. However it does give some indication of what is happening underneath the ball indenter.

One should compare (b) Fig. 223 with Fig. 225 and these two in turn with Fig. 215. In Fig. 225 the light portion directly under the indentation corresponds to the strain area under the indenter in Fig. 218. The light portion under the indenter in Fig. 225 is shown up by oblique illumination and consists of a multitude of fine cracks which are the slip lines in the permanent deformation. These cracks may be seen more clearly in Fig. 226, in which the cracks or slip lines seem to run out from the periphery of the imprint. Not only are the slip lines shown, but also the piling up may be seen in

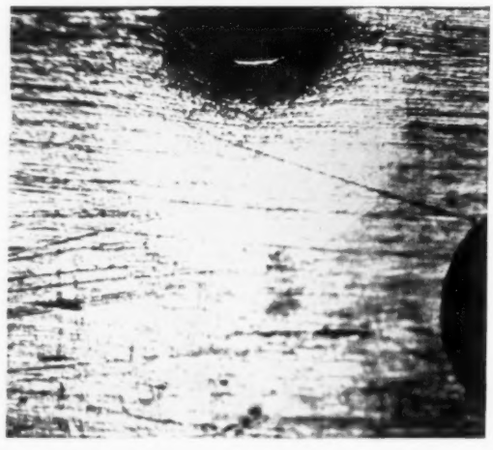


Fig. 225. This photograph shows the stress distribution in a two-dimensional system. A side view of an indentation made by a steel ball.

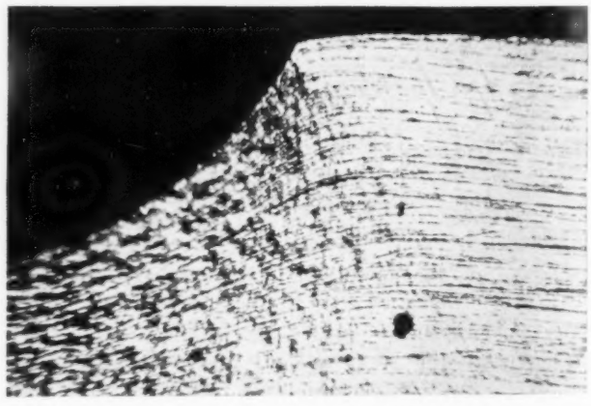


Fig. 226. A vertical cross-section of an indentation made by a steel ball in a block of steel. The piling-up is apparent here in the photograph. The slip lines are represented by the small cracks running out radially from the surface of the imprint.

rofile, since the imprint shown is a vertical cross-section of the space occupied by the ball.

Fig. 227 shows the disturbed area of the surface into which a steel ball has been pushed. Not only are the slip lines intricate and many but they cease abruptly at a definite distance from the periphery of the indentation as was observed in several of the other indentations.

The "piling-up" and the "sinking-in" may also be studied by sensitive dial indicators like the one shown in Fig. 228. In place of the microscope usually employed on a Société Genèvoise dividing engine, a heavy brass shank carries a dial indicator. The lower end of the thrust pin which moves the indicating hand over the dial is carefully ground to a point and then rounded off smooth so that as the traveling table of the dividing engine with the test piece is moved along under the lower end of the thrust pin the latter will not scratch the surface on which the indentation has been produced. As the traveling table of the dividing engine is moved forward by means of the accurately calibrated screw of the engine, the reading of the dial indicator is taken at successive steps in the progress of the traveling table. Fig. 229 shows the readings of the dial indicator in thousandths of an inch as the surface tested is moved forward by steps of one millimeter. The two curves are for the same indentation but with different scales for the ordinates, one in thousandths of inches and the other in thousandths of a millimeter. When both coördinates are to the same scale in the metric system it will be observed that a circle can be drawn which nearly fits the indentation, and which is also nearly the cross-section of the ball making the indentation. There is some flattening to the imprint. See e—(c—b), Fig. 211. It is from such curves as these shown in Fig. 229 that Norbury and Samuels were able to draw their final (eleven) conclusions, chief of which were:

(1) "The 'sinking-in' or 'piling-up' of the material surrounding a Brinell impression have a constant value for a given material irrespective of the size of the impression if expressed as a percentage of the measured depth of the impression." Thus in Fig. 229 the ratio of the height of the curve above the line AB to the depth of C below AB is always a constant for any given substance.

(2) "In cast materials the sinking-in may be as much as 30 percent. In annealed and tempered steels the piling-up is about 10 percent. In cold worked materials the piling-up may be as much as 30 percent."

(3) "The value of n in Meyer's formula,

$$P = a\ d^n,$$

is related to, and varies with, the amount of sinking-in or piling-up."

Foss and Brumfield[5] have made careful measurements on the contours of the surface in and around the impression of a hardened steel ball indenter. This study is noteworthy for its painstaking care and detail in studying minor but essential points.

Fig. 230 is a photograph of a steel ball indentation in cast iron. This is a case of sinking in. The difference

[5]F. E. Foss and R. C. Brumfield, Some Measurements of the Shape of Brinell Ball Indentations. *Proceedings American Society for Testing Materials*, Vol. 22, Part 2, 1922, pages 312-334.

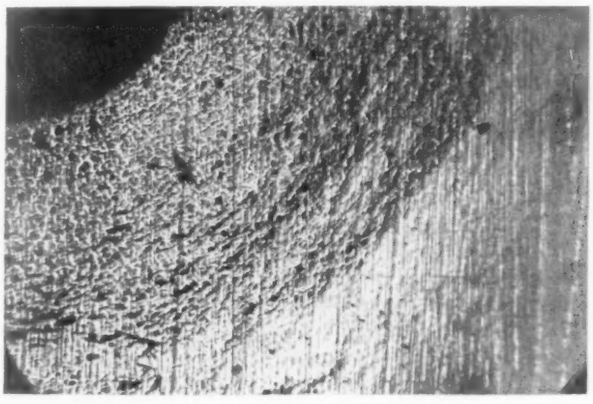


Fig. 227. The upper left-hand corner is one segment of the indentation by a steel ball indenter. Not only is the piling-up shown, but also it may be seen how intricate are the slip lines which correspond to those in Figs. 220 and 221.

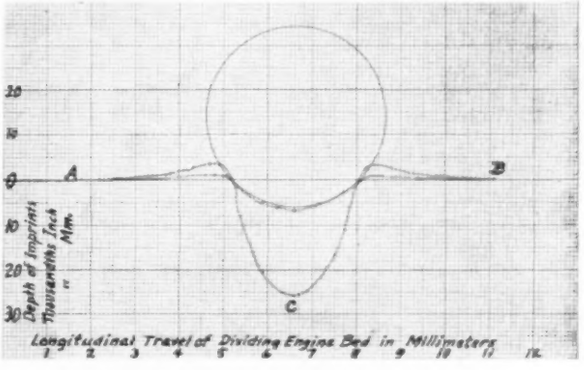


Fig. 229. Contour of indentation by a steel ball.

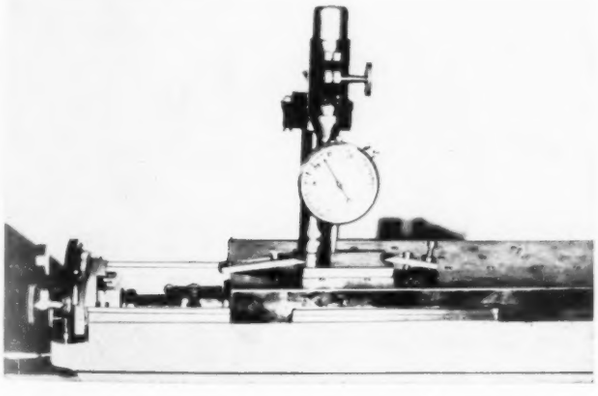


Fig. 228. Dial indicator mounted on a Societe Genevoise dividing engine for measuring the amount of the piling-up or the sinking-in of an impression produced by a Rockwell indenter.

Fig. 230. Surface surrounding the imprint of a steel ball indenter when pushed into cast-iron. This is a case of sinking-in.

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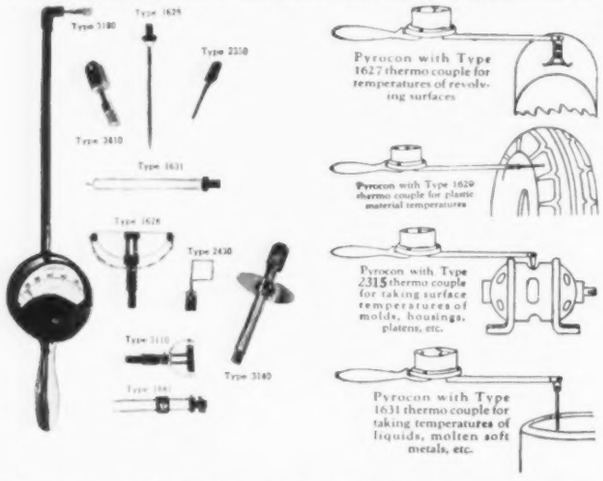
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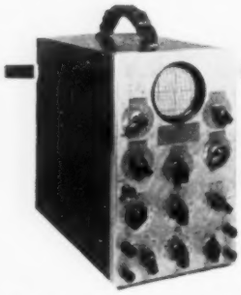

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between this case and the one shown in Fig. 227 is at once apparent. In Fig. 230 may be seen the cracks which open up as the surface bends downward—cracks which are roughly parallel to circles concentric with the circular impression of the ball.

In Fig. 231 appears a magnified image of the imprint of a Rockwell hardness tester (1/16" ball) in a steel surface which had been finished to a mirror surface and flat enough to exhibit Newton's interference fringes between the surface of steel and a piece of optically flat plate glass coated with a "half silvering." It can be seen that the interference bands become finer and closer together at the boundary of the disturbed por-

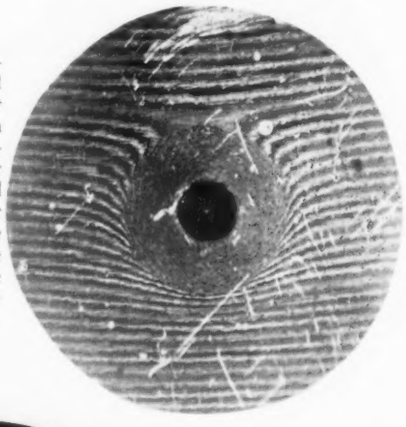

Fig. 231. The imprint of a Rockwell steel ball indenter when made on a steel surface finished to a mirror smoothness and then studied under a half-silvered piece of glass for the contours of the surface around the imprint.

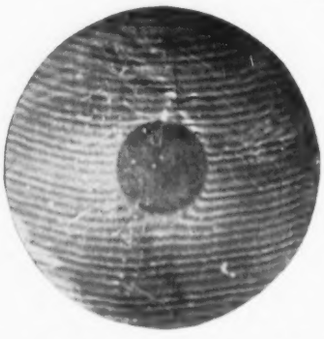

Fig. 232. For comparison with Fig. 231. This is the system of interference fringes around a hole bored into the same piece of steel as was used in Fig. 231.

tion of the surface around the imprint. Wherever the bands thus crowd together into finer and closer formation it means that the two surfaces are farther apart at that point. In this particular case the steel surface has sunk below the main surface by a few wave-lengths of light and this could not be detected by a microscope or a dial indicator, although the piling-up at the edge of the imprint can.

Near the edge of the indentation of the ball, piling-up has occurred to such an extent that due to the roughening of the surface by the slip lines the surface is no longer suitable for reflection and therefore no interference band appear within the disturbed area around the imprint. One has no test by interference for the complete mapping of the contour lines by interference over the entire surface of the disturbed area. The surfaces were illuminated by sodium light in making this photograph in Fig. 231.

Fig. 232 is added to show by comparison how the interference fringes look in the area about a hole which has been drilled through the same block of steel as that shown in Fig. 231. The hole was drilled *before* the polishing was done. It will be noted that the edges of the hole are worn away somewhat more than the main surface in the grinding and polishing process. In Fig. 231 the indentation was produced *after* the grinding and polishing processes.

(To be continued)

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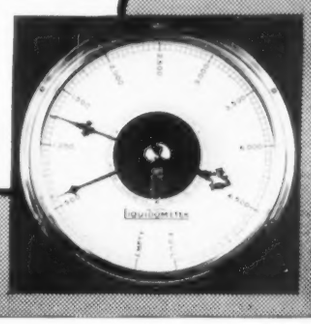

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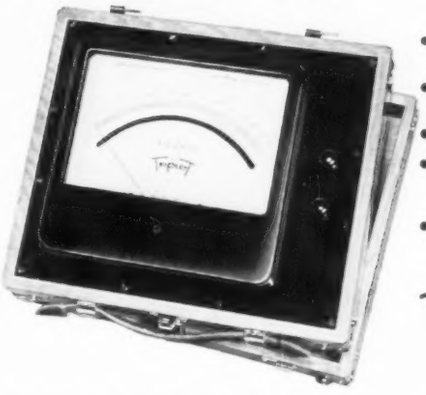

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Continued from page 54

unknown; the battery and ammeter in the main circuit should be of sufficient capacity to handle the current required for accuracy of measurement; the apparatus in the auxiliary circuit would ordinarily consist of a two- or three-cell portable storage battery, a 1-10,000-ohm decade resistance box, and a 20- or 50-milliampere range milliammeter. The polarity of battery connections must be observed.

When X is larger than S, a drop greater than IS must be obtained to balance IX; this additional drop is secured by passing an additional small current, i, through S and in the same direction as the main current I. Then:

$$X = A/B \times S(1 + i/I)$$

If X is less than S, the polarity of the auxiliary battery must be reversed and the expression then becomes:

$$X = A/B \times S(1 - i/I)$$

For accuracy the ratio i/I should be approximately 1/1000;

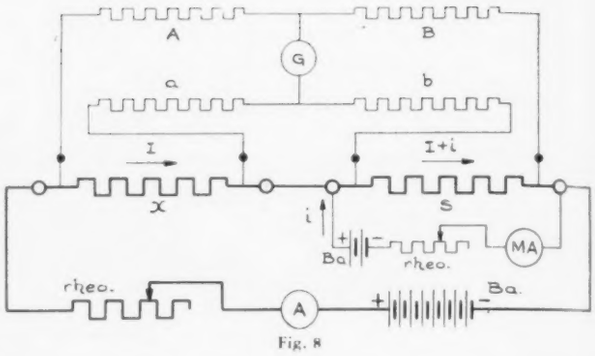

Fig. 8

then the value in the parenthesis of the above expression would be 1.001, and an error of 100% in the measurement of I would result in an error of 0.1% in the determination of the value of the unknown resistance. Thus it can be seen that it does not require the use of precision ammeters. For precision results one should closely observe the current limit for accurate values of the standard.

In the foregoing discussions of the Kelvin Double Bridge, A, B, a, b are actually the resistances of the various resistor coils plus their respective connecting leads. For practical purposes this lead resistance may be neglected; but for precision work, such as comparing standards, it is not negligible. Therefore, even if the ratio arm resistors are adjusted so that $A/B = a/b$, the resistance of the leads and contacts, α, may slightly upset this relation and the effect of α will not be absolutely negligible.

Actually:

$$X = S\,\frac{A_C + A_L}{B_C + B_L} - \frac{\alpha\left(\dfrac{a_C + a_L}{b_C + b_L} - \dfrac{A_C + A_L}{B_C + B_L}\right)(b_C + b_L)}{a_C + a_L + b_C + b_L + \alpha}$$

where the subscript C designates coil resistance, and the subscript L designates the lead resistance.[1]

If the effect of α is entirely eliminated, the adjustment for balance of the bridge will not be disturbed by any value of α, regardless of how large it may be. One method of obtaining this desired condition is to balance the bridge with α closed, and again with it open, thereby having minimum and maximum values. The Reeves Method for adjusting the ratio arms to eliminate α is commonly used. This method calls for successive adjustment of the arms with α closed and open until a balance is maintained with either connection.

Comparing the Kelvin Double Bridge with other methods for measuring low resistance, one might say it requires more elaborate and more expensive apparatus than some of the other simpler methods. On the other hand, some of its many advantages are: results of measurements are most precise and certain, adjustments are easily made, no calibrated instruments are required, absolutely constant current is not necessary, the standard and unknown resistances need not be approximately the same value, it may be obtained in portable form, and it is a null or zero balance method which minimizes the personal error. Taking all considerations into account, the Kelvin Double Bridge is the best method for the accurate, certain, and efficient measurement of low resistance.

[1] Laws, Electrical Measurements, Second Edition, page 192. McGraw-Hill Book Company, Inc., New York, 1938.

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